THE JOHNSON
RECORDING OSCILLOMETER

THE JOHNSON RECORDING OSCILLOMETER

Its Use in the Study of Arterial Circulation

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TABLE OF CONTENTS

PREFACE

The research reported in this monograph was initiated in 1930 when the *author was on the faculty of the Physiology Department of the University* of Chicago as well as on the faculty of the Departments of Physiology and Medicine of Northwestern University The work was continued in private practice and while the author was in the United States Air Force in World War II It was later carried on at the University of Illinois College of Medicine where the author is now a member of the faculty Almost all of the clinical studies were made in the Circulation Laboratories at St Luke s Hospital Chicago or in the author s private practice

The author wishes to acknowledge his indebtedness to his many friends and associates who assisted in the research read the manuscript made helpful suggestions or aided in the technical details He is especially indebted to the Women s Board of St Luke s Hospital and to Dr Selim McArthur who were instrumental in making laboratory facilities available and in providing funds for the initial research to Professor Anton J Carlson and Professor Arno B Luckhardt of the University of Chicago to Dean Irving Cutter of Northwestern University to Professor Andrew C Ivy of the University of Illinois to Mr Howard A Carter and Dr Frederick T Jung of the American Medical Association to the Institute of Biological Research and its technical staff to Professors William and Francis Shonka of the *Department of Physics of the University of Chicago* and to *Miss Gertrude Gscheidle Chief Librarian of the Chicago Public Library*

INTRODUCTION

THE objective of this monograph is to present a detailed description of the Johnson Recording Oscillometer which makes possible the recording of the calibrated arterial volume pulse without arterial puncture from any where in the extremities the temporal artery the brain and the intraorbital tissues This monograph also summarizes published and unpublished data resulting from studies utilizing the Oscillometer some of which may be only of academic interest while other aspects may have a direct clinical application in the diagnosis and treatment of patients

The subject of arterial circulation which includes arterial blood pressure has been of interest since early times Interest in the subject is intensified at the present time because of the growing incidence of arterial disease associated with increased longevity improved methods of diagnosis and the varied surgical and non surgical methods used in the treatment of arterial disease

For the most part the results of the above procedures are assessed by the subjective method only or by objective methods which require arterial puncture Furthermore some of the remedial procedures particularly those related to hypertension are assessed on the basis of studies on the arms only even though it has been known since 1924 that differences in the blood pressure may occur in all four extremities This knowledge is derived from the study by Bazett[1] which showed that differences in the blood pressure in all four extremities may be present in the normal dog The fact that differences in the blood pressure in all four extremities also exist in man has been amply confirmed by others and is re confirmed in this study

Some of the events of the arterial circulation may occur as rapidly as 0 04 seconds This eliminates visual observation on non recording instru ments as a method of study since the human eye cannot detect such rapid changes For this reason a precision timed calibrated recording oscillo meter suitable for clinical studies and known as the Johnson Recording Oscillometer was developed

A search of the literature shows that Swammerdam[ ] (1637–1680) had constructed a similar instrument (see Fig 1) which he used for the study of muscle physiology A significant difference between the Johnson Record ing Oscillometer and that of Swammerdam is in the nature of the recording droplet Swammerdam used water and the Johnson Recording Oscillo

meter uses 95 per cent ethyl alcohol. Both use air conduction to transmit the changes which take place in the confined extremity

The Johnson Recording Oscillometer was originally designed for the study of the arterial circulation in the legs of dogs. It was later modified for studies on the human finger (see Fig 2). The more extensive and diversified use of the Oscillometer was not foreseen when the original equipment was developed and the initial studies on arterial circulation were made[3]

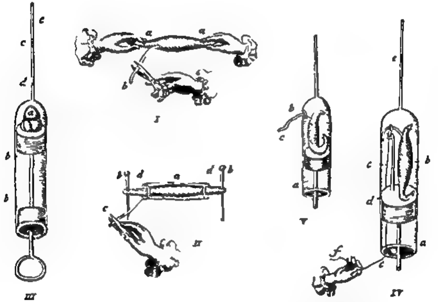


Fig 1

This figure represents a reproduction from Boerhaave's *Biblia Naturae* and shows illustrations of the plethysmographs used by Jan Swammerdam. The text is a literal translation from part of the original text to this figure. I Muscle movement in the frog. *aa* the two muscle tendons grasped by the fingers. *b* when hanging nerve is touched the muscle contraction draws the two hands together. II Method showing thickening of muscle in contraction. *a* Glass tube through which muscle is drawn. *bb* needles transpiercing tendons. *c* the nerve touched. *dd* displacement of needles *bb* as contracting muscle fills up center of glass tube. III Method showing that the heart occupies less space in contraction. *a* Contracting heart is placed upon piston of glass tube. *bb* glass tube. *c* water droplet introduced into tube of siphon descends with heart contraction. *d* place in tube showing distance moved by droplet during time of descent. IV Method showing that contracted muscle takes up less space. *a* Tube. *b* muscle. *c* silver thread through loop of which the nerve is passed. *d* copper thread with loop at top through which silver thread is drawn. *e* water droplet in siphon tube. *f* hand stimulating nerve, muscle contracts and droplet descends a little. V Another method of showing the above. *a* Glass siphon. *b* aperture drilled in the siphon. *c* nerve drawn through the aperture. (Translation of legend by Dr Arno B Luckhardt)

The first description of the instrument for making visual recordings of the arterial volume pulse of the fingers was published in 1931[3] as part of a manuscript on The Effect of Amyl Nitrite on the Finger Volume Since that time the instrument has been adapted to optical recording and has gone through several modifications which were described in 1932[4] 1940[5] and 1951[6]

The instrument was also described in a 1952 report by the Council on Physical Medicine and Rehabilitation of the American Medical Association[7] The Council on Physical Medicine and Rehabilitation in the above report stated Evidence obtained from sources acceptable to the Council indicated that this instrument provides a convenient method for obtaining pulse wave recordings as an aid in the diagnosis of cardiovascular disease

The Oscillometer together with recordings and data taken from cases involving orthopedic surgery were exhibited for a conference of the

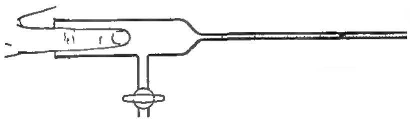


Fig 2

A line drawing of the original digital oscillometer A calibrated glass tube is sealed to one end and a rubber dam attached to the other end is perforated in such a manner that a finger or toe can be inserted into the glass chamber through this perforation as shown A by pass stopcock which is used during adjustments is sealed to the side of the chamber The droplet of 95 per cent alcohol is shown in black for illustrative purposes When the finger or toe is in the chamber as illustrated the droplet of alcohol oscillates with each volume change caused by the increased amount of blood entering the finger with each heart beat This calibrated volume change can be recorded with the latest instrument shown in Fig 3

American Academy of Orthopedic Surgeons in 1951 The exhibit received the Gold Medal Award[8] citing the clinical value of the Recording Oscillometer in Orthopedic Surgery

There is no other equipment which resembles the Johnson Recording Oscillometer in design Instruments operating on different principles have excessive overshoot undershoot and lag Therefore it is not possible to present comparative studies

Because of the physics involved in the dynamics of arterial circulation competent physicists were consulted with the objective of correlating the operation of the instrument with the dynamics of the arterial circulation

The publication of this monograph does not mean that this research project is completed Studies utilizing the Johnson Recording Oscillometer are in progress in the author s laboratory and private practice and elsewhere throughout the world The use of the equipment is not limited to research in the field of organic diseases of the cardiovascular system as is illustrated by a study of allergic manifestation on the cardiovascular system in progress in 1957 under the direction of Dr Grant H Laing at St Luke s Hospital Chicago

In order to evaluate the results of the studies made with the Johnson Recording Oscillometer one must have an understanding of the basic principles involved in the construction of the Oscillometer as well as of the equipment specially built to test the accuracy of the Oscillometer

CHAPTER 1

THE JOHNSON RECORDING OSCILLOMETER

THE Johnson Recording Oscillometer in its simplest form (see Fig 2) was designed for recording the arterial volume pulse from the finger The latest model for recording the arterial volume pulse from the finger is shown in Fig 3 and for recording the arterial volume pulse from anywhere in the extremities from over the temporal artery or from the brain in Fig 9 The instrument as used for recording arterial blood pressure is illustrated in Figs 28 and 30 and for recording the arterial volume pulse from the intra orbital tissues in Fig 53

Each part of the instrument has been constructed to co ordinate precisely with other parts and in relation to the requirements of recording the human arterial volume pulse The timing of the recording is comparable to that of the electrocardiogram or 0 04 sec between divisions

The Calibrated Recording Tube

The calibrated recording tube is of critical dimensions and is accurately calibrated to 0 01 ml The bore cannot be too small so that the effects of capillary action will be introduced nor can it be too large so that the drop let of alcohol will not hold together Two calibrated tubes are available one with a smaller bore (2 1 mm) and greater sensitivity used for infants and children and the other with a larger bore (2 5 mm) used for adults

The Recording Droplet

The recording droplet is 95 per cent alcohol and was selected because it is easily available and has the physical properties necessary for the effective functioning of the Oscillometer It has a low specific gravity thus de creasing the mass per unit which has to be displaced The meniscus of the droplet extends to the ends of the pipette so that the droplet changes form not position as a result of the arterial volume pulse Its solvent properties are such that the walls of the calibrated tube do not collect a film of grease which so commonly happens when water is used The internal resistance of the instrument is largely determined by the menisci of the droplet of alcohol extending to the ends of the calibrated tube In this manner any change in volume affecting the droplet is a change in the form of the droplet (see Fig 4) The resistance to the change in form is largely of a molecular nature and not a resistance of movement of the droplet against the walls of the tube

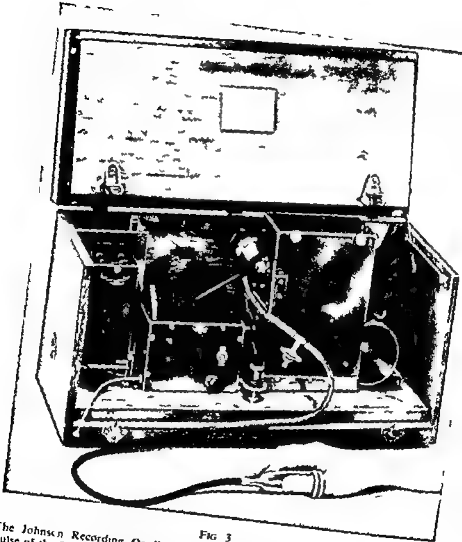


FIG 3

The Johnson Recording Oscillometer arranged for recording the arterial volume pulse of the finger The optical principles are illustrated in Fig 6 and the mechanical details of construction are described in Fig 7

FIG 4

An unretouched photograph taken of the calibrated tube and the recording droplet of al ohol while a recording was being made Note that the menisci of the droplet of 95 per cent alcohol extend to the ends of the tub As a result the droplet changes form instead of position while the volume changes are being recorded

To further demonstrate the lack of resistance the time elapsed for a droplet to fall the length of the recording tube within the tube and in the air in front of the tube under the influence of gravity was determined and found to be approximately the same as illustrated in Fig 5

The Optical System

When a beam of light is cast on the recording tube with the contained droplet of alcohol the calibration lines on the tube intercept the light rays and are transferred to the moving light sensitive paper The droplet of 95 per cent alcohol acts as a plus cylinder lens and focuses the light rays on

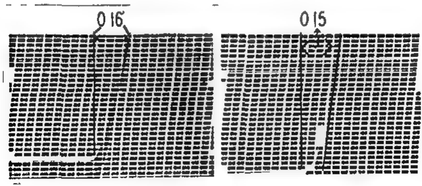


FIG 5

Two recordings made with the Johnson Recording Oscillometer on its side so that the recording calibrated tube was vertical In both instances the droplet was allowed to fall under the forc of gravity In the illustration on the left the droplet fell within the alcohol wetted tube while in the illustration on the right the droplet was allowed to fall in front of the tube Note that the time of fall was approximately the same in both cases illustrating the fact that the " alcohol wetted tube offered no more resistance to the falling droplet than the air surrounding the droplet

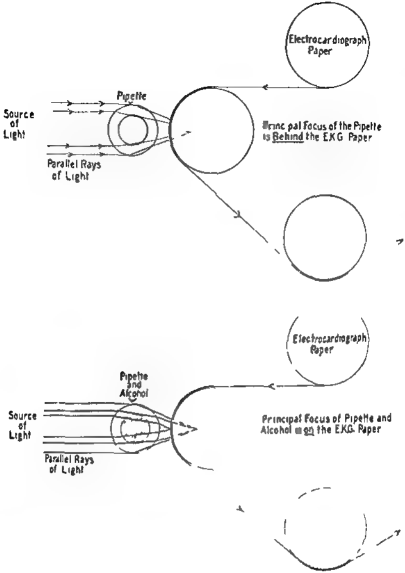


FIG 6

The simplicity of the optical system of the instrument is illustrated above Note that the parallel light rays passing through the walls of the pipette only do not focus on the light sensitive paper while those passing through the walls of the tube and the droplet come to focus on the light sensitive paper The volume calibrations on the tube intercept the light rays In this manner the droplet of alcohol produces a sharp intense black image on a light background with lines representing volume differences The recording is timed with vans intercepting the light rays from a synchronous timer with intervals of 0·04 sec similar to the timing of the electrocardiogram

the moving sensitive paper A synchronous timer with vans spaced to produce time intervals of 0 04 sec is placed so that it will intercept the rays of light The exposed and developed photosensitive paper reveals the following horizontal lines with a volume of difference between any two lines of 0 01 ml vertical lines with a time difference of 0 04 sec between any two lines and a sharply defined black image which represents the droplet of alcohol These optical principles are illustrated in Fig 6

The optical slit is fixed at 0 0015 in By using intense illumination in relation to daylight the instrument can be used in broad daylight without visibly affecting the recording The possibility of making recordings without darkening the room is advantageous in that it avoids influencing the patient s psychosomatic state thus obtaining better controls

The instrument has eight rapidly interchangeable speeds varying from 1 4 to 5 2 cm/sec The high speeds spread the recordings of individual pulse waves and thus make possible the more detailed analysis of a single pulse wave The high speeds are also useful when recording very rapid heart rates as illustrated in Fig 16

In order to have approximately the same developing time for the exposed paper regardless of the speed used easily interchangeable light filters (see Fig 7) are built into the instrument By using the dark filter for the four low speeds and the light filter for the four high speeds approximately the same density is obtained on the developed paper

The Oscillometer has a built in synchronous timing device designed to produce the same time interval as the electrocardiogram or 0 04 sec (see Fig 7)

The Transmitting Device

With chambers suitable for the fingers and toes and a special chamber for the intraorbital tissues recordings can be made directly from the calibrated tube In order to transmit the arterial volume pulse from other parts of the extremities the temporal artery or the brain it is necessary to use a special transmitting device constructed in the following manner

The transmitting device (see Fig 7) has two chambers The inner chamber is of a size and elasticity and is biased in such a way that it has practically the same sensitivity throughout the entire range of diastolic blood pressure It can also record systolic blood pressure over 300 mm Hg The outer chamber has a standard aneroid Tycos Blood Pressure Dial built in This chamber is of such dimensions in relation to the inner chamber and to the pickup mechanism as to affect a reduction of the arterial volume pulse when using the 12 cm blood pressure cuff of about 10 1 for adults and a reduction of about 5 1 when using the 8 cm cuff for infants and children

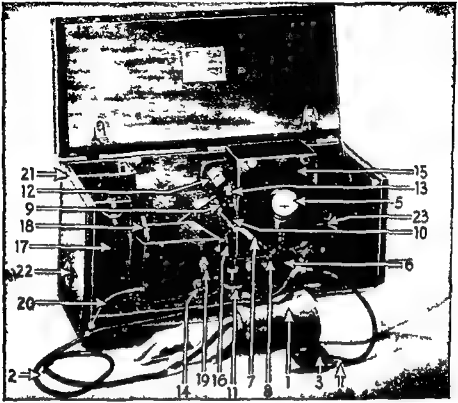


FIG 7

This illustration shows the component parts of the Johnson Recording Oscillometer (1) a reinforced Tycos Blood Pressure Cuff 12 cm wide (?) one of the rubber tubes which connects the cuff to the transmitting device of the Oscillometer (3) the inflating bulb (4) an escape valve for adjustments (5) a Tycos blood pressure dial connected to the transmitting device (6) the double transmitting chamber with a reduction of about 10 1 (7) a rubber tube connecting the transmitting device to the calibrated recording tube containing the recording droplet of 95 per cent alcohol (8) a by pass stopcock for adju tments (9) the recording tube (10) the recording droplet of 95 per cent alcohol (11) the leveling screw for the camera (1) a measuring device giving the inches of exposed paper (13) a numbering device for marking the tracings (14) a red light which turns on when the paper is exhausted in the instru ment (15) the camera box (16) a disk containing the vans of the synchronous timer (17) the light source (18) the interchangeable filte (19) a switch to turn the light source off and on (20) the cable release which turns on the timer and operates the camera (21) the cabinet enclosing the in trument (2) an inlet socket for 110 V 60 cycle current

The Camera

The camera mechanism is so constructed that it uses standard 50 ft rolls of 6 cm daylight loading cartridges of electrocardiograph paper (Camco No 30) Mechanical provision is made for a positive drive of paper at a uniform predetermined speed through the camera The exposed paper enters a removable light proof chamber which has a self contained paper-cutting device When the recording has been made this chamber can be removed and the paper taken to a darkroom for development Furthermore a numbering mechanism is built into the camera so that the

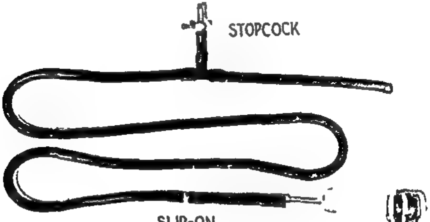


Fig 8

This figure illustrates the detail of the "pickup" mechanism for making recordings of the arterial volume pulse from the digits The digit is inserted into the glass chamber through the hole in the rubber dam while the slip on connector is detached The open end of the rubber tubing is connected to the calibrated recording tube while the adjusting stopcock is left open The patient is made comfortable to avoid tremor and movement the slip on connector is attached the droplet of alcohol in the calibrated recording tube is centered the stopcock is closed and the recording made

tracings are marked for identification The illumination is provided by a standard light bulb with a fixed resistance in series so that the life of the light source is over 1000 hr Suitable lenses concentrate the beam of light on the recording mechanism A cable release operates the camera (see Fig 7) The entire apparatus is operated on 110 V 60 c/s alternating current

The Pickup Mechanism

The pickup mechanism varies in accordance with the part of the body from which recordings of the arterial volume pulse are to be made

The mechanism used for the fingers and toes (described in material published in 1932[11]) consists of a glass chamber which fits over the extremity One end forms an airtight seal over the finger or toe by means of a rubber dam The other end is connected to the recording instrument by rubber tubing with a suitable by pass for adjustment (see Fig 8)

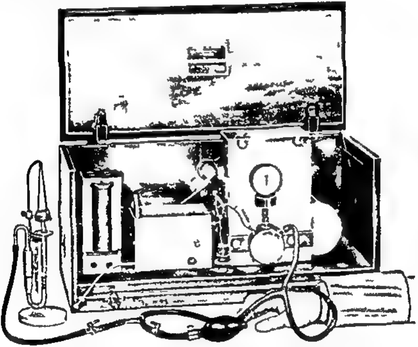


Fig 9

This illustration shows the procedure for making recordings of the diastolic blood pressure and the arterial volume pulse from anywhere in the extremities except the fingers and toes In this illustration recordings are being made from the right wrist

The pickup mechanism which is used for recording the arterial volume pulse from the intraorbital tissues the temporal arteries and the forehead is specially constructed and is described in detail in Chapter IX and is illustrated in Fig 53 This mechanism is also connected to the recording instrument by means of rubber tubing with a suitable by pass for adjustments (see Fig 53)

The pickup mechanism for recording the arterial volume pulse and the arterial diastolic pressure from anywhere in the extremities, the temporal artery, or the brain has been described in previously published material[6] but briefly consists of a 12 cm Tycos Reinforced Blood Pressure Cuff for adults and a 6 cm blood pressure cuff for premature babies, infants, and children (see Fig 9). It would be desirable to have the latter cuff reinforced but none are available at this writing.

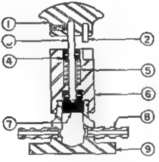


Fig 10

A machine drawing of the metering device which accurately delivers 1 ml or ½ ml volume change at will by merely depressing the plunger (1) knob, (2) stop pin, half volume, (3) piston rod, (4) retaining collar, (5) compression spring, (6) upper body, (7) Teflon piston, (8) hose ends, and (9) lower body.

Calibration

The recording tube is accurately calibrated to 0.01 ml. The pickup chambers for the fingers, toes, and intraorbital tissues are connected directly to this tube when recording from these areas. The transmitting device described above is included in the system when making recordings of the arterial volume pulse from the arms and legs (exclusive of the fingers and toes), from the temporal artery, and from the brain, and when recording blood pressure in the arms and legs. In the early models of the Oscillometer, recordings were individually calibrated by means of a 2 ml syringe containing oil (see Fig 9). The calibration was set at 1 ml when using the 12 cm Tycos Reinforced Blood Pressure Cuff for adults, and at ½ ml when using the 6 cm cuff for premature babies, infants, and children. The calibration was made by depressing the plunger of the syringe while the recording was being taken. In the later models, a calibrating device of

greater precision is built into the mechanism. This device, which does not require a reservoir of oil, is illustrated in Fig. 10.

Projection of Recordings

The arterial volume pulse can be projected on a screen for visual observation by groups by means of a lantern slide adapter. The adapter with a built in leveling adjustment replaces the lantern slide conveyor and carries the calibrated recording tube. A holder for the transmitting device is connected to the adapter (see Fig. 11).

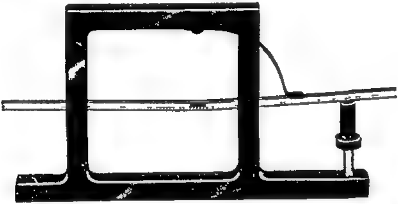


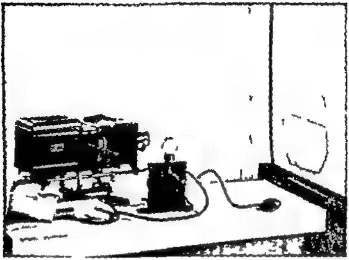
FIG. 11

A special frame to carry the recording tube of the Oscillometer has been constructed to replace the standard slide carrier of the lantern slide projector as illustrated above. The pipette (1) is connected to the transmitting mechanism. By this means the arterial volume pulse can be projected on a lantern slide screen as illustrated in Fig. 12.

The results of a visual recording of the arterial volume pulse and blood pressure made during a critical cardiac operation on an infant at the Children's Memorial Hospital, Chicago, was previously reported in 1951[6] and is reproduced in Fig. 12. From such visual recordings an experienced observer can predict well in advance from disturbances of the cardiac rhythm and blood pressure the impending collapse of a patient.

The Cabinet

The entire equipment described above is contained in a cabinet with dimensions of $22 \times 9.5 \times 9.5$ in., which weighs 35 lb. For convenience a special table has been constructed so that the instrument can be rolled to the patient's bedside (see Fig. 13).



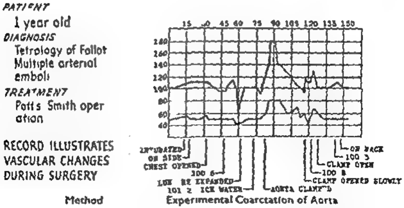


Fig. 1.

The means of projecting the arterial volume pulse on the screen is illustrated at the left of the figure and the data thus obtained during a critical operation on a one year old infant is shown at the right

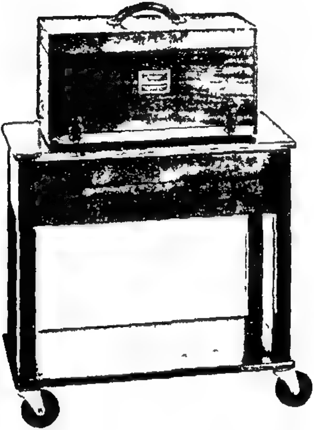


FIG 13

This figure shows the entire unit enclosed in a cabinet on a movable table which can be rolled to the patient s bedside

CHAPTER II

CHARACTERISTICS OF THE JOHNSON RECORDING OSCILLOMETER

Lag

The term "lag" as used in this monograph indicates the time elapsed from the arterial volume pulse in the subject to the time of recording. The arterial volume pulse is taken up by the pickup mechanism of the Oscillometer and travels through the instrument with the speed of sound. This was confirmed experimentally by making simultaneous recordings of the electrocardiogram and the arterial volume pulse while using 5 ft of tubing and while using 55 ft of tubing from the patient to the instrument. The peak of the R wave of the electrocardiogram was used as a point of reference. From the time difference (0.04 sec) of the two recordings the speed of the transmission of the arterial volume pulse in the instrument can be computed and the lag thus determined. The instrument is ordinarily used with 5 ft of tubing. The lag is then 0.004 sec. This figure is insignificant and not measurable. When using less tubing the lag is approximately 0.002 sec. A typical experiment is illustrated in Fig. 14.

Natural Period of the System

The inertia of the contained air and recording droplet of alcohol is so small as compared to the inertia of the pickup unit (Tycos Reinforced Blood Pressure Cuff) that the natural frequency of the transmission tubing would be much greater than any heart rate encountered in man. The pickup unit (blood pressure cuff) is never moving under forced vibration and therefore its natural frequency is not a factor.

Responsiveness to Various Pulse Rates

The instrument will record volume pulse rates of over 1000 per minute. The average normal human subject can produce voluntary clonus in the arm with rates up to 500 contractions per minute. By tapping the inflated pickup mechanism of the Oscillometer while so doing the contractions will be recorded. Such a recording is shown in Fig. 15.

There has been no opportunity in this study to make recordings of the arterial volume pulse in many patients with heart rates of over 200 per minute. In one patient with auricular fibrillation the rate between two single beats was the equivalent of 250 beats per minute. This was recorded

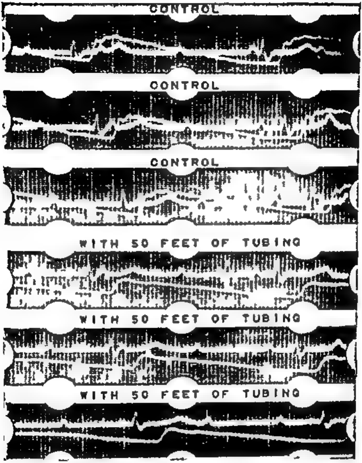


FIG 14

This illustration shows the manner of determining the lag of the Oscillometer Simultaneous recordings of the electrocardiogram and the arterial volume pulse from above the right elbow were made using five feet of tubing from the patient to the recorder and were repeated while using fifty additional feet of tubing From point of reference on the electrocardiogram one can determine the time required for the arterial volume pulse to travel 50 ft which is approximately 0 04 sec As the instrument is ordinarily used with 5 ft of tubing the lag is 0 004 sec This is insignificant and not measurable

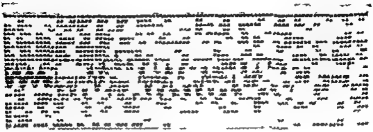


FIG 15

These recordings were made to show the responsiveness of the Oscillometer to rapidly induced volume changes The recording cuff was wrapped around a rigid tube about the size of the human arm and inflated to 100 mm Hg to simulate the diastolic blood pressure Rapidly induced volume changes were produced by tapping the cuff at rates of about 500 per minute

by the Oscillometer and is shown in Fig 16 . Rates such as this are seldom observed but this case does illustrate the need for the higher speed in the instrument to provide for the accurate timing in such cases

Extremely slow heart rates occasionally occur Fig 17 illustrates the arterial volume pulse recordings from a patient in whom the heart rate of the dominant beat and of the coupled beat was 26 respectively making the combined rate 52 per minute This recording illustrates the fact that the coupled beat may contribute materially to the minute arterial volume pulses Several patients with complete heart block have been studied A recording

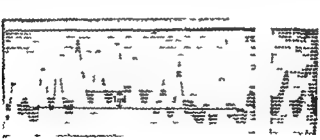


FIG 16

Recording taken from above the right elbow in a seventy five year old female with auricular fibrillation and cardiovascular failure with edema It represents the arterial volume pulse with an average heart rate of about 150 but in the recording on the right between the two beats shown it represents a heart rate of 250 This demonstrates that the Oscillometer is capable of recording any known human heart rate It is not possible to make an accurate calibration of the recording in the presence of auricular fibrillation but a rough approximation can be made as shown

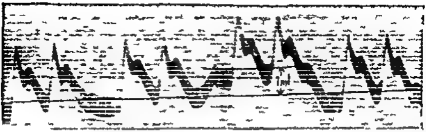


FIG 17

Recording of the arterial volume pulse taken from above the right elbow in a sixty seven year old white male who had a history of a slow irregular heart beat The electrocardiogram showed a sinus mechanism with coupling. Note that the rate of the dominant rhythm is 26 per minute and of the coupled rhythm 26 per minute making a total of 52 beats per minute *In this case the coupled beat is a very efficient beat* and contributes about 46 per cent of the minute arterial volume pulses The corrected minute arterial volume pulses in this case are 166 ml which is within the normal range

of the arterial volume pulse in one of these cases showing a heart rate of 33 per minute is illustrated in Fig 18

Sensitivity

The Oscillometer is not equally sensitive at all cuff pressures It is less sensitive with the higher cuff pressure as shown in Fig 19A However the sensitivity is fairly constant in the range of diastolic blood pressure

The amount of air in the pickup mechanism affects to some extent the sensitivity of the Oscillometer When the pickup is applied snugly the Oscillometer is more sensitive to volume changes than when the cuff is applied loosely as illustrated in Fig 19A-1 Observations made in the course of these studies indicate that the extremity can change in size rapidly due to shifts in tissue fluids It is obvious that the sensitivity of the recordings would change if this occurred

FIG 18

Recording of the arterial volume pulse taken from above the right elbow from a sixty five year old coloured female with complete heart block During the recording a superimposed volume change was induced into various phases of the cardiac cycle In no instance did this induced volume change alter the recording for more than one cardiac cycle

When the *6 cm cuff is used the amount of air in the system is markedly* reduced and the sensitivity of the Oscillometer is markedly increased as shown in Fig 19B The above factors illustrate the need for calibrating each recording individually thus eliminating these conditions as sources of error In the instance of the 6 cm cuff the desirability of using ½ ml for calibration instead of 1 ml as is used for the 12 cm reinforced cuff is also apparent

The size or volume of the recording droplet has very little effect on the *sensitivity of the Oscillometer The size of the droplet is usually 0 04 ml*

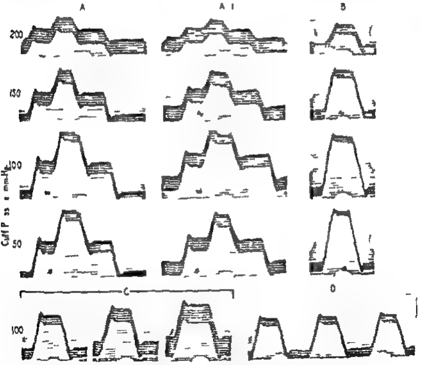


Fig 19

These recordings illustrate the sensitivity of the instrument Recording A shows that the Oscillometer used with the 12 cm cuff is not equally sensitive at all cuff pressures and is more sensitive at cuff pressures in the range of diastolic blood pressure Recording A 1 shows that an increased amount of air in the pickup cuff reduces the sensitivity Recording B shows that the use of the 6 cm cuff markedly increases the sensitivity of the instrument Recording C shows that the size of the recording droplet does not affect the sensitivity of the instrument Recording D shows that repeated similar volume changes produce identical results *Note* 1 ml volume change was used in every case

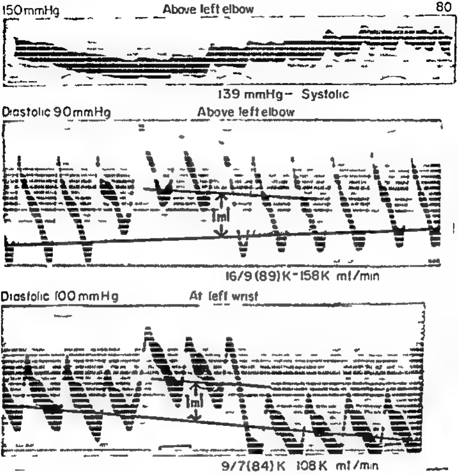


FIG 0

Recordings made of the arterial blood pressure and arterial volume pulse above the left elbow and at the wrist in a seventy five year old white male with severe Parkinson's disease In most cases severe tremor is not an obstacle in obtaining good recordings

and a slightly smaller or larger droplet has very little effect as shown in Fig 19c

The width of the recording surface of the photosensitive paper is 6 cm and the recording of any arterial volume pulse is limited to this distance which represents 0 28 ml with the calibrated tube of large bore and 0 19 ml with the calibrated tube of small bore At any given pressure the

sensitivity is the same throughout this range as illustrated in Figs 19A 19A – 1 and 19B

Repeated similar volume changes produce identical results as illustrated in Fig 19D

Responsiveness to Extraneous Factors

Extraneous factors which might be thought to modify the recordings do not do so because of the characteristics of the Oscillometer The following examples serve as illustrations (1) A single induced extraneous volume change while making a recording of the arterial volume pulse will not modify the recording for more than a single beat since it does not cause the instrument to oscillate as shown in Fig 18 (2) It is possible to obtain good recordings of the arterial blood pressure and the arterial volume pulse in severe Parkinson s disease as shown in Fig 20 (3) It is possible to make recordings of the arterial volume pulse from the arm while the patient is walking around the room if the subject can keep his arm relaxed (4) It is possible to make recordings of the arterial volume pulse through heavy clothing with some loss of sensitivity This procedure is cited merely to demonstrate the sensitivity of the instrument

Errors Due to Overshoot

As used in this monograph the term overshoot refers to the recording droplet going beyond the actual arterial volume pulse change The overshoot due to various components of the Oscillometer namely the calibrated recording pipette the transmitting device and the pickup mechanism (Tycos Reinforced Blood Pressure Cuff) has been determined

The overshoot in the calibrated recording tube is negligible when a fixed volume is introduced at various rates and the time of rise of the volume recording is more than 0 1 sec As will be brought out in the chapters on the recording of the arterial volume pulse from the fingers and toes and from the intraorbital tissues the time of rise of this component of the arterial volume pulse is always more than 0 1 sec For this reason overshoot does not introduce any error when taking recordings from these areas as illustrated in Fig 21

The overshoot for the combination of the calibrated recording tube and the transmitting device was determined by injecting a fixed volume of air at various rates It was found that the degree of overshoot varied with the crest time (time of rise of the volume pulse) as shown in Fig 21 There is considerable overshoot with crest times comparable to those found in the human arterial volume pulse taken in the extremities exclusive of the fingers and toes

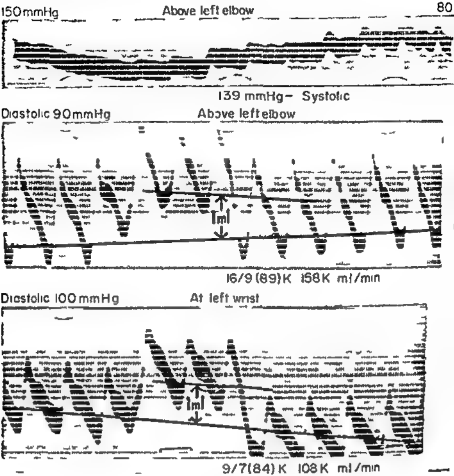
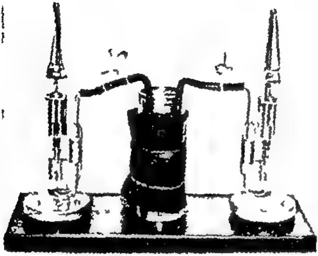


FIG 20

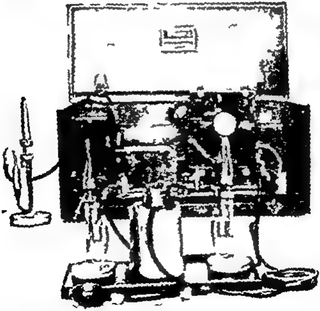
Recordings made of the arterial blood pressure and arterial volume pulse above the left elbow and at the wrist in a seventy five year old white male with severe Parkinson's disease In most cases severe tremor is not an obstacle in obtaining good recordings

and a slightly smaller or larger droplet has very little effect as shown in Fig 19c

The width of the recording surface of the photosensitive paper is 6 cm and the recording of any arterial volume pulse is limited to this distance which represents 0 28 ml with the calibrated tube of large bore and 0 19 ml with the calibrated tube of small bore At any given pressure the



A



B

3

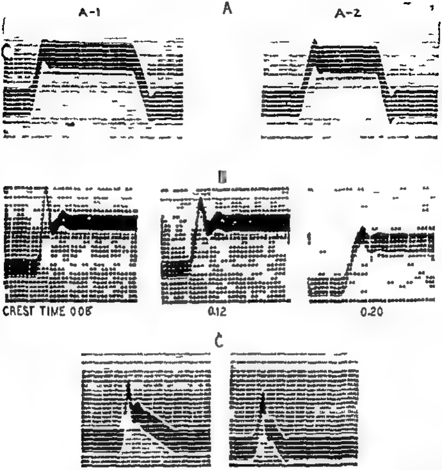


FIG. 23

Recordings made from the artificial arm for the calibration of the Oscillometer to illustrate the effects of "overshoot," "run off" and the artificial pulse waves which can be produced under controlled conditions.

A. Recording A-1 shows a calibration of the Oscillometer to 1 ml and recording A-2 shows a calibration of the artificial arm to 1 ml. Note that the amplitudes are identical indicating that there is no loss in transmission of 1 ml from the artificial arm to the recording mechanism.

B. These recordings show the effects of crest time on the degree of overshoot. Similar studies at various crest times and various diastolic pressures produce the data which makes it possible to compute correction factor A (see Fig. 24).

C. These recordings show pulse waves produced from the artificial arm. The proximal syringe was depressed so that the crest time was 0.18 sec in each case. The recordings simulate heart rates of 53 and 89 respectively. Note the difference in amplitude which is accounted for by the difference in "run off." Also note the presence of a dicrotic notch which is similar to that seen in the human pulse wave.

artificial arm with a rigid tube two inches in diameter around which the rubber portion of a standard 12 cm blood pressure cuff is wrapped The proximal outlet is connected to a hypodermic needle which can be changed at will and which acts as a resistant to the flow of fluid The hypodermic needle is in turn connected to a reservoir and a 2 ml syringe The whole system contains 100 ml of water with all air excluded through by pass stopcocks It has been found that this equipment will function satisfactorily with volumes of fluid in the system ranging from 50 to 125 ml Greater or less fluid brings about other technical difficulties The equipment is shown in Fig 22A In operation the pickup mechanism of the Oscillometer is wrapped around the rubber cuff as in making recordings from the human arm as shown in Fig 22B

The following procedures are possible with the above combination of instruments

1 The diastolic pressure can be controlled by inflation of the Oscillometer cuff to the desired pressure

2 When the syringes of the artificial arm are set at 1 ml and the diastolic pressure is set at a selected level injection of 1 ml into the artificial arm while recording on the Oscillometer gives a value corresponding to 1 ml as calibrated by the Oscillometer itself as shown in Fig 23A

3 The crest time or time of rise of the volume pulse can be controlled by the rate of injection It is then possible to determine the degree of overshoot with different crest times as shown in Fig 23B

4 The simulated heart rate can be controlled by changing the peripheral resistance The constriction of a 20 gauge hypodermic needle will give a simulated volume pulse rate of about 100 per minute while a 22 gauge needle will give a simulated rate of about 50 per minute as shown in Fig 23C

5 An artificial precision volume pulse can be produced by depressing the distal syringe While recording the proximal syringe is depressed and the distal syringe is released and takes up the volume of 1 ml at a rate determined by the peripheral constriction or heart rate In this manner volume pulses simulating those seen in almost any cardiovascular condition can be produced at will as shown in Fig 23C

Errors Due to Undershoot

Undershoot is comparable to overshoot except that it occurs during diastole if the descent of the volume pulse is rapid when a fast heart rate

is present It is negligible in recordings of the arterial volume pulse from the fingers toes and *intraorbital tissues* In the extremities exclusive of the fingers and toes it does become a factor in heart rates of over 100 as illustrated in Fig 23c The degree of undershoot has also been determined for various heart rates and enters into the computation of the correction factor K (see formula in the legend for Fig 24)

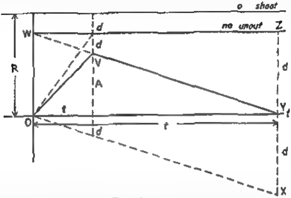


Fig 24(A)

An analysis of the arterial volume pulse for overshoot and run off from which the correction factor K is obtained to construct the graph shown in Fig 24(B)

The triangle OYX can be constructed equal and congruent to triangle WYZ if and only if OX is parallel to VY and the extension of VY meets WZ on the vertical axis through O

Then $d/d = t/t$

Note The triangle OYX did not need to be constructed to prove this but the assumption as made above is necessary in order to set up the proportion

In terms of a correction factor K defined by

$$d = K(d \quad d_2 - d)$$

then $$K = d/(d + d - d)$$

since $$d = 1 \text{ ml}$$

$$K = 1/(d - d - d)$$

Errors Due to Runoff

In this monograph the term runoff refers to that quantity of blood which moves forward without contributing to the expansion of the arterial tree during each systole It represents the effects of the kinetic energy as contrasted with the potential energy as a result of the expansion of the arterial tree to accommodate the increased amount of blood ejected by the heart during systole This is difficult to determine precisely experimentally An approximation can be determined on the artificial arm as shown in Fig 23c or it can be computed as being the ratio of the crest time over the length of the cardiac cycle multiplied by the calibrated recorded volume pulse

Determination of the Correction Factor K

In the preceding paragraphs it was pointed out that overshoot can be determined experimentally for different crest times and undershoot can be determined experimentally for different heart rates. Runoff can be computed and varies with both crest time and heart rate. *K* has been determined from the formula in the legend for Fig 24A.

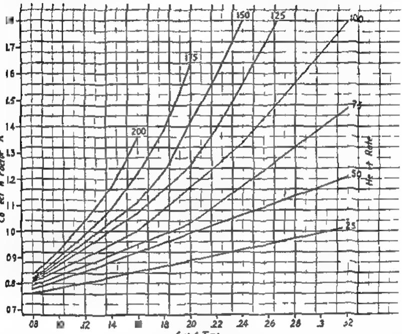


Fig. 24(B)

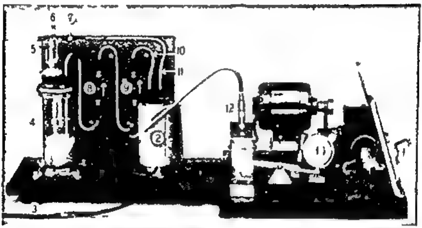
Graph giving K for various crest times and various heart rates. The runoff *d* was computed from the formula set forth in Fig 24(A) and *d* and *d* were determined experimentally. The correction factor *K* is for overshoot and runoff for heart rates of less than one hundred beats per minute. The correction factor *K* for heart rates over one hundred beats per minute includes overshoot, runoff and undershoot.

The correction factors for various heart rates and crest times are shown in Fig 24B. The cuff pressures used made no appreciable difference in the results.

Equipment for Testing Accuracy

In order to test the accuracy of the Oscillometer in recording the calibrated arterial volume pulse an artificial circulation instrument was made simulating the human circulation as closely as is mechanically possible

The apparatus used the principle of the artificial arm illustrated in Fig 22 but incorporated a mechanical pump with which it is possible to deliver a fixed volume pulse at various crest times and various heart rates The system contains two one way flutter valves which provide for flow in only one direction The opening and closing of these valves sound much like the tones of the human heart The peripheral resistance can be modified at will by means of a needle valve The instrument can be set at any desired diastolic pressure various heart rates and various crest times Continuous recordings from the artificial arm of this apparatus can be made



1 Interchangeable Cam
2-Blood Pressure
3 To Oscillometer
4 Reservoir

5 Return Flow
6 Needle Valve
7 Cut Off Valve
8 Flutter Valve

9 Flutter Valve
10 To Artificial Arm
11- From Artificial Arm
12 Syringe

FIG 5

The equipment built to simulate the human systemic circulation The drive mechanism with multiple speeds is shown on the right and has a replacable cam (1) which activates the plunger of a syringe (12) through a lever mechanism The form of the cam can be computed from human arterial volume pulse recordings Recordings made from this instrument by means of the Oscillometer simulate the arterial volume pulse recordings in every detail Any human arterial volume pulse can be duplicated on this instrument The flow through the simulated extremity is in one direction only controlled by means of two flutter valves located in (8) and (9) The needle valve (6) controls the peripheral resistance and returns the fluid to the reservoir (4) The pickup mechanism of the Oscillometer is shown surrounding the simulated human extremity at ( )

on the Oscillometer and the recordings can be calibrated at will The simulated venous return can be collected and compared with the computed volume pulse from the Oscillometer recordings From this study it was determined that the error was less than 7 per cent with heart rates under 125 The precision instrument described above is shown in Fig 25

CHAPTER III

THE ARTERIAL PRESSURE PULSE AND THE ARTERIAL VOLUME PULSE

SOME difference of opinion exists concerning the distinction between the arterial pressure pulse and the arterial volume pulse Arterial pressure pulse and arterial volume pulse are intimately related and have the same origin namely the action of the heart In the arterial system the speed of the arterial pressure pul e is in part determined by the decree of existing elasticity The speed of the arterial pressure pulse can be measured in experimental models of the arterial circulation and in patients as illustrated in Fig 26

Because of the action of the heart and because of the anatomical structure of the arterial system both arterial pressure pulse and arterial volume pulse are created with each heart beat

The Pressure Pulse

The pressure pulse is created by the action of the heart suddenly ejecting additional blood into the elastic arterial system already under pressure This pressure pulse travels down the arterial system with a speed of from 15 to 60 ft/sec and has been measured by others It can be measured by the Johnson Recording Oscillometer as shown in Fig 26 The measurement is made by taking simultaneous electrocardiograms and volume pulses above the elbow and at the wrist and noting the lag in the pressure pulse between the two areas from a point of reference on the electrocardiogram The distance between the elbow and wrist can be measured and from these figures one can compute the speed of the pressure pulse wave The pressure pulse contributes virtually nothing to the forward flow of blood

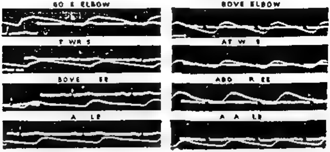
Although a great deal has been written concerning the pressure pulse no clear cut definition can be found in the literature as the term is used in this study

Force and pressure are both involved in the genesis of the pressure pulse Force is generally defined as push or pull Forces are usually expressed in pounds grams or kilograms Pressure means the push or pull on a unit of surface acted upon Pulse is generally defined as a regular beating or throbbing caused in the arteries by contraction of the ventricles of the heart

Therefore a pressure pulse could be defined as a push or pull on a unit area of the surface of an artery caused by the contraction of the ventricle

SPEED OF THE PULSE WAVE

NORMAL	HYPERTENSION
AGE 77 CUFF PRESSURE 70 MM. HG	AGE 76 CUFF PRESSURE 100 MM. HG.



	Elbow Wrist		Knee Ankle		Elbow Wrist		Knee Ankle	
BLOOD PRESSURE	110/60		120/80		154/92		220/140	
TIME PEAK OF R WAVE TO BEGINNING OF PULSE WAVE	14	.17	19	.21	.12	.14	.17	.19
DIFFERENCE IN SECONDS	.09		02		.02		.02	
DISTANCE IN INCHES	11 25		11 75		10.75		13 00	
RATE OF PULSE WAVE IN FEET PER SECOND	31 30		32.80		45.00		54 00	

Fig 26

This illustration shows the manner of measuring the speed of the arterial pressure pulse (not to be confused with the arterial volume pulse) The distinction between the two is illustrated in Fig 27 Simultaneous recordings of the electrocardiogram and the arterial volume pulse are made from above the elbow and at the wrist From a point of reference on the electrocardiogram the time elapsed for the pulse wave to travel from the elbow to the wrist can be measured The distance in inches can also be measured From these figures the speed of the pressure pulse can be computed The same procedure can be used on the leg Illustrative cases are shown in the table

of the heart However this must be modified in view of present knowledge to include in the concept of pressure pulse the delivery of blood from the left ventricle to the aorta

The Volume Pulse

The literature contains much material on the change in volume of the arterial tree as a result of the action of the heart However the relationship of the pressure pulse to the genesis of this change has not been clearly defined

For the purpose of this study the standard definition of volume and pulse apply namely volume is defined as space occupied as measured in

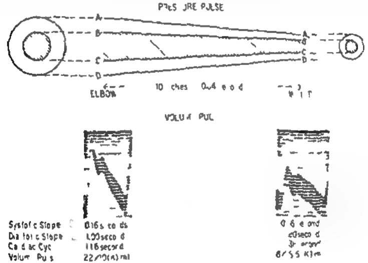


FIG 7

The upper line drawing was made to illustrate a hypothetical cross section of the arterial tree above the elbow and at the wrist during diastole (B C) and (B -C) and during systole (A-D) and (A D) Note that the pressure pulse travels from the elbow to the wrist *in* 0 04 *sec* On the other hand the volume pulse above the elbow and at the wrist takes *0 16 sec to reach a peak which is a reflection of the* maximum distension of the arterial tree in these locations

cubic units The term volume pulse is defined as is the term pulse in Webster's Dictionary *i e* a regular beating or throbbing caused in the arteries by the contraction of the ventricles of the heart The arteries already being filled with blood under pressure the additional quantity of blood forced into them by each ventricular contraction causes a distension of the arterial walls These contracting again under their own elasticity force the blood along distending in turn the part of the artery next beyond

the institution of the auscultatory technique by Korotkov[11] in 1905 the era of modern clinical sphygmomanometry began

Until 1924 it was assumed that no significant differences in the arterial blood pressure in the arms and legs in the reclining subject existed At this time Bazett[11] by direct arterial puncture in dogs in the horizontal position showed that the systolic pressure was higher in the femoral artery than in the brachial artery *but that the diastolic pressure was the same*

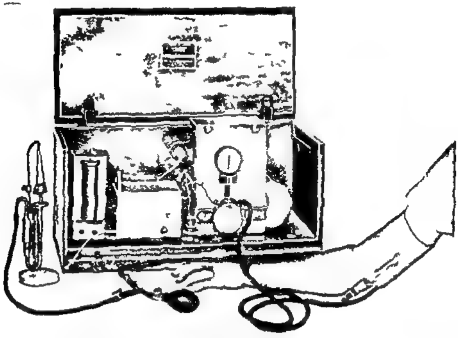


FIG. 8

The instrument arranged for taking the diastolic blood pressure and the arterial circulation from above the elbow Recordings thus taken are illustrated in Figs 9 and 4

throughout the arterial tree Previous isolated reports on human subjects with aortic regurgitation as well as hyperthyroidism had been reported with the same findings

Comparative studies on arterial blood pressure by the auscultatory techniques and direct arterial puncture were made possible after the development of the *Hamilton Manometer*[12] *Numerous authors (Burdick*[13] Strang[14] and Hamilton[15]) have consistently found the blood pressures higher in the legs than in the arms of normal reclining subjects

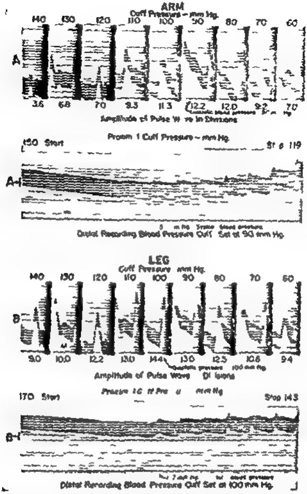


FIG. 29

Pulse wave recordings from which the arterial blood pressure can be determined A and B are pulse wave recordings at 10 mm Hg cuff pressure increments from 140 mm Hg down to 60 mm Hg above the elbow and above the knee respectively The maximum amplitude of the pul e wave in the arm is recorded at 90 mm Hg which is the diastolic blood pressure and at 100 mm Hg in the leg which is the diastolic blood pressure A-1 and B-1 are recordings of the pulse wave below the elbow and below the knee respectively when known constrictions are applied above the elbow and above the knee by second cuffs as illustrated in Fig 30 In the illustration for the arm (A-1) the pressure in the proximal cuff was 150 mm Hg when the recording was started and 119 mm Hg when it was stopped The recorded strip of tracing represents 31 mm Hg and the systolic blood pressure is interpolated at 136 mm Hg A similar study in the leg gave a systolic blood pressure of 157 mm Hg pressure Note the subject for this recording was a normal white male age 31 70 in tall and weighing 180 lb

The proper width of the cuff for taking blood pressure has been the subject of much controversy. At present the 12 cm cuff is recommended for the arm and the 15 cm for the leg. In a study by Sapp, Arney and Mattingly[9] published in 1955 an 18 cm cuff was advocated for the leg. Erlanger and Hooker[16] stated that if the artery is compressed as much as 4 cm the cuff is adequate. Wiggers[17] is of the opinion that the 13 cm cuff is adequate.

Attempts have been made to record the diastolic blood pressure by oscillometry, using the pressure at which the maximum pulse wave was recorded as the diastolic pressure (Janeway[18], Masing[19], Sahli[20] and Marey[21]).

Reviews of the subject of arterial blood pressure have been written from time to time, including a study by the Committee of the American Heart Association[22] in the *Standardization of Blood Pressure Readings*. A review of the subject in monograph form was published by Masters *et al*[23] in 1952.

Method of Recording by Oscillometry

In the work reported in this monograph, the arterial blood pressure in the arms and legs is recorded by oscillometry. In this method the recording of the diastolic blood pressure is based on Marey's Principle[21] which states that "application of a definite force to an elastic vibrating structure causes it to oscillate most extensively when internal and external pressures are equal." This is a physiological application of Hooke's Law from physics which states that "if a displacement of an elastic body occurs, the restoring force is proportional to it within the elastic limit of the body." Periodic wave motion requires that this condition exist, as is the case when the cuff is at the diastolic pressure. From this discussion it is apparent that it is only necessary to discover at what cuff pressure the maximum amplitude of the pulse wave occurs. A standard 12 cm Tycos Reinforced Blood Pressure Cuff is applied above the elbow in the usual way and is attached to the Oscillometer, as shown in Fig. 28. Recordings of one or two arterial volume pulses at cuff pressures ranging from 140 to 60 mm Hg, taken at 10 mm Hg increments, are made, as shown in Fig. 29. The amplitude of the recorded arterial volume pulse is measured with a caliper and the pressure level at which the maximal pulse wave is recorded is the diastolic blood pressure. The same procedure is carried out above the knee to obtain the diastolic pressure, as shown in Fig. 29.

The systolic blood pressure is recorded by means of the Oscillometer using the double cuff method, as shown in Fig. 30. A standard 12 cm Tycos Reinforced Blood Pressure Cuff is applied above the elbow in the usual way and is connected to a standard aneroid blood pressure dial. The

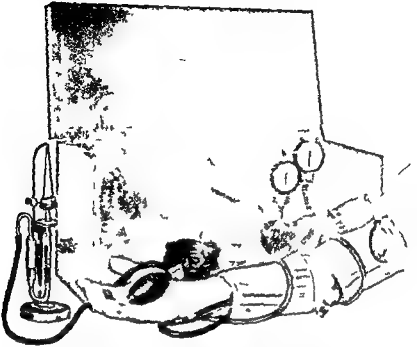


FIG 30

This photograph shows the manner of applying the pickup cuff for the recording of the systolic blood pressure The distal cuff is inflated to approximat ly the diastolic pressure and is used for recording The proximal cuff is inflated to a pressure above the level at which no recording of the pulse beat is made by the di tal cuff The proximal cuff is deflated slowly while a recording is being made and the level at which the first beat is registered by the distal recording cuff is taken as the systolic blood pressure as shown in Fig 29

system is modified by incorporating a by pass air escape mechanism by which the pressure can be reduced at a uniform rate by merely opening a valve as shown in Fig 31 A second standard 12 cm Tycos Reinforced Blood Pressure Cuff is applied below the elbow and is connected to the Johnson Recording Oscillometer To obtain a recording of the systolic blood pressure the distal cuff is inflated to the diastolic blood pressure as previously determined The proximal cuff is inflated to above the antici pated systolic blood pressure and a visual note is made of this pressure Recordings from the distal cuff are made while the proximal cuff is deflated at a fixed rate until recordings of the arterial pulse wave appear from the distal cuff A visual observation is made of the pressure in the proximal cuff at the point at which the recording is stopped The cuff pressure in

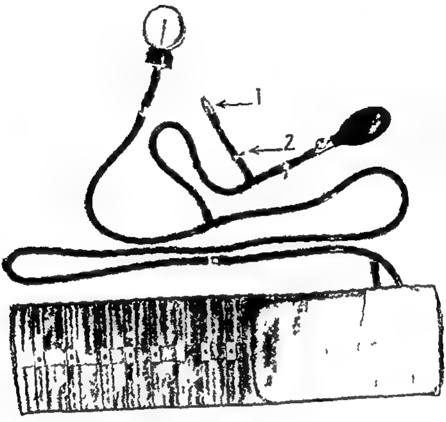


FIG. 31

This figure illustrates the detail of the proximal blood pressure cuff and accessories used in recording the systolic blood pressure as shown in Fig 30 The by pass con striction (1) can be altered at will by using various sizes of hypodermic needles In most instances a 27 gauge needle is used To record the systolic blood pressure the instrument is arranged for recording from the distal blood pressure cuff set at approximately the diastolic blood pressure The proximal cuff is inflated to above the anticipated systolic pressure Re ordings from the distal cuff are started simul taneously with the opening of the by pass valve ( ) and continued until recordings of the volume pulse from the distal cuff appear A note is made of the pressure in the proximal cuff at which recordings were started and stopped From the devel ped record one can interpolate the systolic pressure

the proximal cuff at the point when the recording was started and stopped is then known The systolic pressure can be interpolated from this re cording as shown in Fig 29 The same procedure can be carried out in the legs and with smaller cuffs on infants and children While carrying out the procedure in the leg the proximal cuff will transmit an impulse

through the table which will be recorded by the distal cuff and give false readings This error can be eliminated by placing a pillow under the knee

All studies were made on adults in the reclining position Some subjects were normal some had cardiovascular disease and others had diseases unrelated to the cardiovascular system The results of the studies are given in Table I These indicate that normotension hypotension and hypertension may exist in the same patient When the data on all four extremities are examined all combinations are found to be present in some patients regardless of adult age sex height body build and weight (Note except Case 11 a seven year old child)

Table I

Blood Pressure Studies

Cases				Blood pressure			
				Arm		Leg	
Case	Col	Sex	Age	Right	Left	Right	Left
				NORMAL IN THE ARMS AND LEGS			
1	W	F	6[illegible]	130/90	11[illegible]/90	145/110	149/100
2	W	F	54	112/90	115/90	142/90	138/90
3	W	M	58	127/100	125/90	148/1[illegible]0	147/100
4	W	M	54	1[illegible]5/80		138/90	143/90
5	C	F	54	1[illegible]7/90	13[illegible]/90	134/90	148/100
6	W	F	53	137/90	1[illegible]5/70	1[illegible]8/80	145/80
7	W	F	34	112/90	1[illegible]0/90	146/80	154/90
8	W	F	57	1[illegible]9/80	131/80	150/90	146/90
				NORMAL IN THE ARMS—HYPERTENSION IN THE LEGS			
9	W	F	54	141/80	138/90	205/110	19[illegible]/110
10	W	M	60	135/100		234/1[illegible]0	
11	W	M	7	135/90	135/90	172/90	160/80
12	W	M	63	140/80	131/90	170/100	157/100
13	W	M	50	131/100	130/100	166/100	168/110
				HYPERTENSION IN THE ARMS AND LEGS			
14	W	F	80	[illegible]40/170		300+/170	
15	W	F	60	185/110		260/140	
16	W	F	53	230/120		[illegible]52/140	
17	W	F	65	173/110	186/90	[illegible]13/100	193/90
18	W	M	59	178/100	164/100	2[illegible]4/110	[illegible]11/110
19	W	F	64	187/110	163/1[illegible]0	139/100	156/110
20	W	F	75	158/80	158/80	214/90	[illegible]01/100
21	W	F	61	300+/180	300+/170	300+/160	300+/
22	W	F	63	187/100	187/110	215/100	2[illegible]6/100
23	C	M	42	155/150	166/150	[illegible]16/160	2[illegible]/160

Blood Pressure Studies—*continued*

Cases				Blood pressure			
				Arm		Leg	
Case	Col	Sex	Age	Right	Left	Right	Left
OCCLUSIVE ARTERIAL DISEASE—ONE OR MORE EXTREMITIES							
24	W	F	42	131/90	131/90	80/60	75 50
25	W	M	71	191/100		275/110	119/110
26	W	M	50	171/100	175/100	160/110	161/110
27	W	M	63	110/80		102/70	166/110
28	W	M	67	128/78	78/70	Amp	107/80
29	W	M	76	180/90	180/100	110/90	115/90
30	W	M	64	160/100	133/90	198/120	[illegible]07/120
31	W	M	50	130/90		139/90	91/70
32	W	M	63	183/100	172/110	117/90	190/80
33	W	M	66	188/90	164/100	127/100	123/100
34	W	M	55	1[illegible]6/80	1[illegible]5/80	107/60	78/60
35	W	M	66	[illegible]05/130	[illegible]/140	97/70	145/90
66	W	M	75	175/80	161/80	109/80	165/80
OCCLUSIVE ARTERIAL DISEASE—COARCTATION OF THE AORTA							
37	W	M	23	207/110	199/110	119/110	1[illegible]1/110
MISCELLANEOUS—MITRAL COMMISUROTOMY—1 YEAR POST OPERATIVE							
38	W	F	1[illegible]	111/70	120/70	160/70	160/70
MISCELLANEOUS—MILD HYPERTHYROID							
39	W	F	56	154/110	165/110	[illegible]17/1[illegible]0	[illegible]07/120
MISCELLANEOUS—POSSIBLE ADRENAL INSUFFICIENCY							
40	W	F	[illegible]4	94/80	10[illegible]/80	1[illegible]1/80	1[illegible]6/80
MISCELLANEOUS—COMPLETE HEART BLOCK							
41	C	F	50	185/100		[illegible]53/110	
4	W	M	65	173/110	186/90	[illegible]13/100	193/90
43	W	M	69	[illegible]05/100	[illegible]16/100	238/100	[illegible]06/110
MISCELLANEOUS—DISK SYNDROME							
44	W	M	50	1[illegible]5/70		159/90	145/90
45	W	M	60	115/90	118/90	183/100	181/100
MISCELLANEOUS—EXTENSIVE THIRD DEGREE BURNS OF LEGS							
46	W	M	34	125/80	138/90	14[illegible]/100	16[illegible]/90
47	W	M	46	116/80	11[illegible]/80	16[illegible]/80	156/90
48	W	M	30	130/90	125/80	155/100	165/90
49	W	M	27	135/90	140/110	191/110	167/100
MISCELLANEOUS—SCLERODERMA—SCLERODACTYLIA—RAYNAUD'S SYNDROME—CALCINOSIS							
[illegible]	W	F	61	132/80	1[illegible]8/90	200/100	18[illegible]/90
RAYNAUD'S SYNDROME IN THE FINGERS ONLY							
51	W	F	49	1[illegible]4/90	13[illegible]/100	148/100	145/100

The preceding table illustrates the differences in arterial blood pressure in the four extremities which one might encounter when the blood pressures are recorded oscillometrically with the standard 12 cm Tycos Reinforced Blood Pressure Cuff

Some of the cases are of unusual interest as indicated below

Case 11 This is the only child in the series and is of unusual interest because hypertension exists in the legs even though the subject was only seven years old

Cases 24–36 inclusive : All had symptoms of intermittent claudication and in addition cases 24 25 28 29 33 34 and 35 had rest pains

Cases 25 and 33 These two cases received hypotensive drugs with an aggration of the intermittent claudication and rest pains which lasted several weeks after cessation of therapy

Cases 24 26 and 35 These cases had lumbar sympathectomies without relief of symptoms

Case 37 This case had a resection of the coarctation which relieved the symptoms and confirmed the diagnosis

Case 50 This case had a bilateral sympathectomy to both arms about twenty years previous with no relief from the Raynaud s Syndrome

The patients varied in adult age (except Case 11) sex body build height and weight although there were no cases of extreme obesity in this entire series

Evaluation of Findings

Although the results produced by oscillometry may not quantitatively reflect the arterial blood pressure it is believed that they are more accurate than when the arterial blood pressure is taken by the auscultory method when similar cuffs are used The data indicates that the difference in the blood pressure in the arms and legs of some patients is so great that errors in the oscillometrical method are insignificant by comparison

The method described uses mechanical principles for recording the arterial blood pressure while the auscultory method relies on the production of sound within the range of hearing known as the Korotkov sounds[11] It would seem that these may vary in pitch and intensity depending on the speed of the rise of the pulse wave as well as the damping effect of the surrounding tissues If the speed of the rise of the pulse wave is much over 0 16 sec (normal 0 08–0 16) the sounds may not be heard

This is well illustrated from records taken from the legs in patients with coarctation of the aorta Case 37 of this series had a speed in the rise of the pulse wave above the knee of 0 24 sec In six other patients with coarctation it averaged 0 25 sec in the legs This is also apparent in patients with occlusive arterial disease where distal to the occlusion the time of rise is markedly prolonged as in cases 24–36 of this series where the time of rise of the pulse wave ranged from 0 2–0 32 sec in the affected extremity This is also true for palpation of the peripheral arterial pulse as the palpating finger cannot feel the slowly rising pulse wave The obvious conclusion is that if the Korotkov sounds are not in the range of hearing the arterial blood pressure must be recorded mechanically

The sensitivity of the instrument for recording systolic arterial blood pressure is approximately 0 02 ml escaping past the proximal blood pressure cuff which means that in taking systolic blood pressure the error is less than 2 mm Hg The sensitivity for recording the diastolic blood pressure is within 10 mm Hg

The instrument used in this study is a precision instrument for the recording of the arterial volume pulse but the pickup mechanism (Tycos Reinforced Blood Pressure Cuff) may introduce significant error because of faulty design or dimensions in relation to the extremity It is significant to note that in the series of patients reported on Table I cases 1–8 varied in adult age height body build and weight Likewise in the rest of the patients who showed abnormalities of blood pressure in the extremities these abnormalities showed no relation to adult age (note case 11 is the seven year old child) height sex body build or weight Furthermore patients 27 28 29 and 34 were studied once a month for more than two years with consistent results within the range of physiological variation For these reasons it would seem that the standard 12 cm cuff gives clinically consistent results for the recording of the arterial blood pressure in all four extremities

A great deal of the work which has been done by others on hypertension was based upon blood pressure studies in the arms only with a disregard of the blood pressure in the legs . It seems apparent that if hypertension of the arms is important hypertension of the legs is equally important perhaps more so when one considers the large amount of arterial pathology in the legs as compared with that seen in the arms On the other hand patients have been observed with hypertension of the arms and hypotension of the legs associated with occlusive arterial disease Such patients when treated with hypotensive drugs may develop an inadequate arterial circulation in the legs with further symptoms of rest pains and intermittent claudication They may develop psychosis brought about by impaired circulation to the brain as in cases 25 and 33

It is significant that the following combination of arterial blood pressure in the arms and legs has been recorded

1. Normal in arms and legs
2. Normal in the arms and hypertension in legs
3. Normal in the arms and hypotension in the legs
4. Hypertension in the arms and legs
5. Hypertension in the arms and normal in legs
6. Hypotension in the arms and hypertension in legs
7. Significant differences in the two arms
8. Significant differences in the two legs
9. Significant differences in all four extremities

These findings are important because they emphasize the need for blood pressure studies throughout the entire body in order to completely evaluate the patient's state of arterial blood pressure and to bring about a better understanding of the nature of arterial blood pressure *per se* This study is a step in this direction

CHAPTER V

THE RECORDING OF THE ARTERIAL VOLUME PULSL FROM THE FINGERS AND TOES

THE recording of the arterial volume pulse from the fingers and toes is especially significant for the following reasons (1) the method of making these recordings involves a different procedure from those used for making recordings from other parts of the body (2) the nature of the arterial volume pulse is different from those elsewhere in the body and (3) the clinical usefulness of this procedure is somewhat less than that of the procedure used for recording the arterial volume pulse elsewhere in the extremities except when disturbances in the arterial circulation of the digits *per se* exist

Method of Recording

Recordings of the arterial volume pulse can be made from the fingers with the patient in reclining sitting and standing positions but for the sake of uniformity and better control the recordings are usually made with the patient in the reclining position after a suitable rest period In order to avoid tremor in the recording as well as the effects of respiratory movements the hand is placed on a pillow laid over the abdomen A droplet of 95 per cent alcohol of a volume of 0 04 ml is placed in the calibrated recording tube and the instrument is adjusted with the leveling screw as shown in Figs 3 and 7 so that the droplet moves slowly toward the operator under the force of gravity The movement of the droplet is stopped by an offset device built into the recording tube The tracing is numbered with the built in numbering device for identification (see Fig 7) The digital chamber has a rubber dam placed over one end with a hole just large enough to admit the digit The seal between the rubber dam and the walls of the digital chamber must be airtight since even a small leak will interfere with the recording This can be insured by wrapping a piece of adhesive tape around the seal The digital chamber is applied to the finger with the by pass stopcock open (see Fig 8) and is connected to the recording tube The instrument is so hinged that the side toward the operator can be elevated In this manner the recording droplet can be moved to the center of the recording tube The by pass stopcock is closed the light switch (see Fig 7) is turned on and the cable release is depressed setting the instrument in motion and making the recording If there is a leak in the system which may happen due to faulty application

of the rubber dam to the walls of the digital chamber or of the digital chamber to the finger the droplet will slowly move toward the operator and no pulsations will be seen Corrective measures are then taken

A normal tracing from the fingers before and after the application of local heat is shown in Fig 32 This illustrates the fact that the arterial volume pulse varies with the size of the finger but averages 0.02 ml for a 20 ml finger In the absence of organic occlusion local heat increases the arterial volume pulse indicating vasodilatation Re application of the

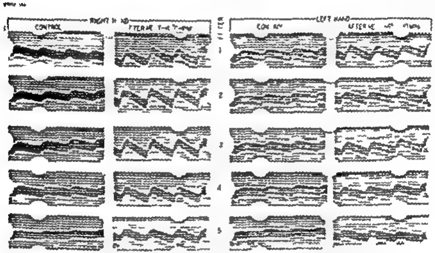


FIG 32

Recording of the finger volume pulse in a normal male The black area represents the width of the recording droplet of ethyl alcohol and does not enter into the measurements Measurements are made from the depression to the peak of the oscillations The horizontal lines are projections of the graduations on the recording pipette and the distance between any two lines is 0.01 ml The vasodilating effects of local heat are well illustrated in this record by the increased amplitude of the excursions

digital chamber followed by arterial volume recordings produces consistent results

The Nature of the Arterial Volume Pulse from the Fingers and Toes

The contour of the arterial volume pulse from the fingers and toes is usually smooth without visible or prominent secondary waves as is frequently not the case in recordings of the arterial volume pulse from elsewhere in the extremity However peaks frequently appear following

vasodilitation from local heat general heat fever nerve block and with some organic diseases of the heart such as high grade aortic regurgitation (see Fig 33) The crest time or time of rise of the arterial volume pulse from the fingers and toes is usually more than 0 2 sec while the normal values from elsewhere in the extremities fall between from 0 08 to 0 16 sec This is important since it precludes overshoot as an error in the recordings Undershoot also is insignificant since the time of descent of the arterial volume pulse is usually longer than 0 2 sec

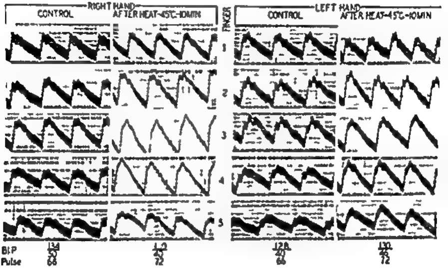


Fig 33

This figure illustrates the exaggerated finger volume pulse from patients with severe aortic regurgitation These changes are a reflection of the increased stroke output of the heart Local heat produced a mark d vasodilatation

The arterial volume pulse in the finger can be obliterated by the application of pressure to the arms by means of a blood pressure cuff This obliteration is complete when the pressure in the cuff is at the systolic level (see Fig 34)

The effects of artificial fever produced by general heat as well as foreign protein on the arterial volume pulse of the fingers has been studied The results were reported in 1935[24] There is an immediate increase in the arterial volume pulse with artificial fever produced by all methods except by the foreign protein reaction in which case there is a preliminary decrease followed by an increase

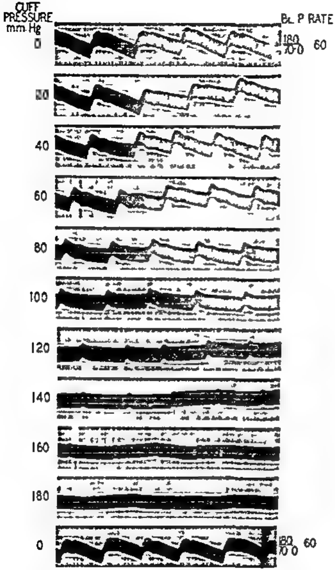


FIG 34

Volume pulse recordings from the third finger of the right hand from a colored male age 39 who had a *luetic aneurysm of the aorta with an acquired communication between the aortic aneurysm and the pulmonary artery* 1 5 by 0 6 cm proven at a subsequent post mortem examination The recordings were made during compression of the upper arm with a blood pressure cuff at 10 mm Hg increments Note the gradual decrease of the amplitudes with obliteration of the volume pulse as the systolic blood pressure was reached and the reappearance of the volume pulse when the pressure was released

The arterial volume pulse from the fingers can be increased by the elimination of vasoconstrictor tone with median nerve block at the wrist through the use of novocain as shown in Fig 35 In this instance the arterial volume pulse becomes greater in the first four fingers and less in the fifth apparently because the blood is shunted into the first four fingers

Further studies were made on the effects of the release of vasoconstrictor tone in a patient with rheumatoid arthritis following unilateral cervical sympathectomy From this study[1, 53] it was found that the arterial volume pulse returned to its control level in twenty eight days following surgery

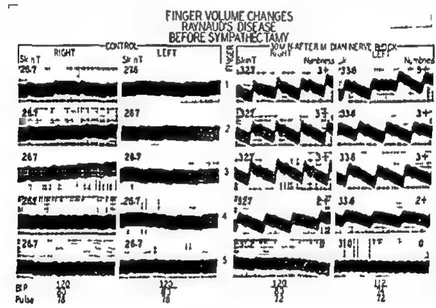


FIG 35

Recordings of the volume pulse from all of the fingers as well as the skin temperatures made from a white male age 47 with Raynaud's symptoms before and after median nerve block at the wrist Note the markedly increased volume pulse from the first three fingers less increase in the fourth and no change in the fifth after the median nerve block

(see Fig 36) Furthermore the arterial volume pulse responded to local heat after this period as did the ones of the control hand However artificial fever induced with foreign protein did not produce increased arterial volume pulse in the sympathectomised finger comparable to the ones seen in the control fingers of the other hand Finally the patient showed no clinical improvement following the surgery

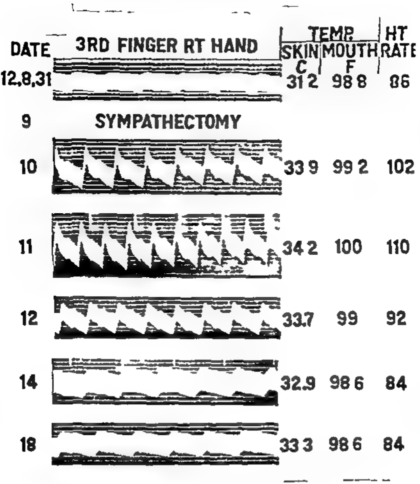


FIG 36
This figure illustrates the change in the arterial volume pulse in the third finger of the right hand in a white female age with rheumatoid arthritis The recordings before and after removal of the right superior cervical and first and second thoracic sympathetic ganglia Note that the volume pulse returned to its control level in 28 days

The arterial pulse from the fingers may be altered by cardiac lesions (see Fig 33) This illustration indicates marked increase in the arterial volume pulse before and after the application of local heat in a patient with high grade aortic regurgitation Also as illustrated in Fig 37 the arterial volume pulse in the fingers in a patient with complete heart block shows a more than normal amplitude as a result of the increased stroke output

of the heart which compensates for the slow heart rate It is further increased after the application of local heat

Raynaud's Symptoms

In 1941[6] a report of "A Study of the Clinical Manifestations and Results of Treatment of Twenty two Patients with Raynaud's Symptoms" confirmed the opinion of Hutchinson[7] that what is now known as Raynaud's disease[8, 9] is not a clinical entity and that the peripheral manifestations observed are merely symptoms of a more fundamental disease

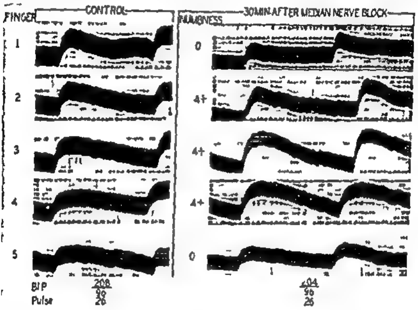


FIG 37

This figure shows the effect of median nerve block on the finger volume pulse in a patient with complete heart block Note that the control finger volume changes are about twice normal This is interpreted as being due to the increased stroke output of the heart to compensate for the slow heart rate Median nerve block produced a moderate increased amplitude of the pulse wave in the middle three fingers which is interpreted as vasodilation

Five of the patients included in this study had surgery of the sympathetic nervous system without relief of symptoms It was indicated in the above report that the symptoms may be caused by a passive vasoconstriction in the fingers due to a vasodilatation in the palmar arch with diversion of blood from the fingers This is contrary to the generally accepted explanation that the symptoms are due to an *active vasoconstriction of the digital* arteries

Since the above report was published seventy five additional patients with Raynaud's symptoms have been studied. In ten of the latter cases the arterial volume pulse at various levels in the entire upper extremity during the digital ischemia was recorded.

The followup on the original twenty two cases was carried on as long as possible. All of the patients improved on medical management or learned

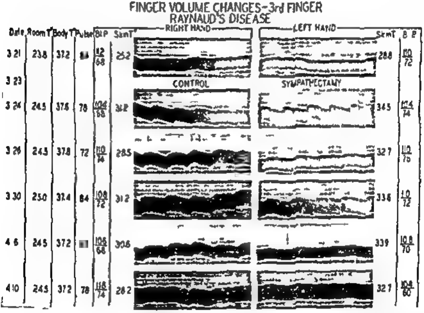


FIG 38

The effects of removal of the stellate and second dorsal sympathetic ganglia on the body temperature, the skin temperature of the third finger of both hands, the pulse and blood pressures. The right side was used for a control. Note that the body temperature and pulse did not change appreciably, that the skin temperatures of the third finger of the left hand, which was also true of the other fingers, remained elevated above that of the right hand, and that the finger volume pulse increased somewhat immediately following the operation but in 18 days returned to their control levels. A similar operation was later done on the right side.

to live with their condition, particularly when they were assured that they were not going to lose their fingers. The surgical cases did not do any better than the non surgical cases. One of the surgical cases stayed under observation for eighteen years and another for ten years. It is of interest to note that the first case did not sweat in the sympathectomised areas for

eighteen years after surgery None of the twenty two original cases or seventy five succeeding cases developed gangrene of the fingers other than the slight flecking of tissues on the terminal phalanges seen on rare occasions

It is of further interest to note that the increase of the arterial volume pulse following sympathectomy of the arm is only of short duration being less than thirty five days in all cases as illustrated in Figs 38 and 39

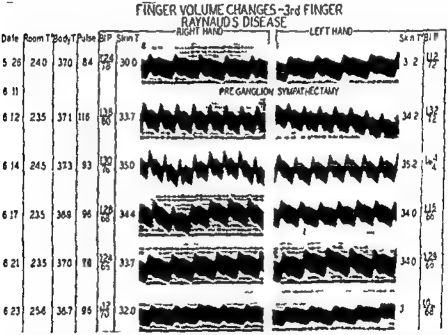


Fig 39

The effects of the preganglionic type of sympathetic operation in which the sympathetic chain was severed below the third thoracic on both sides Note that there were no changes vascular or otherwise which persisted beyond the traumatic effects of the surgery

Of the additional patients only three were of unusual interest Two were female one white and one colored with associated lupus erythematosis In one male patient with gout the Raynaud s symptoms cleared up promptly on the control of the gout

Studies of the arterial volume pulse at various levels in the arms as well as in the fingers during the digital ischemia in ten patients with Raynaud s symptoms all gave consistent results namely the arterial volume pulse was

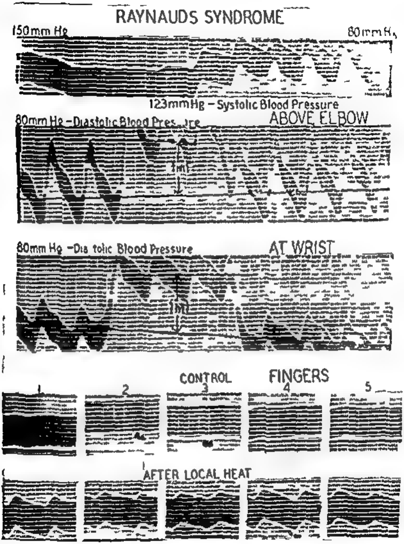


FIG 40

A composite study of the recorded arterial blood pressure the minute arterial volume pulses above the elbow and at the wrist and the pulse volume changes of the fingers of the right arm in a white female age 33 during an attack of Raynaud's symptoms. The recorded arterial blood pressure was 123/80 the minute arterial volume pulses above the elbow 94 ml at the wrist 33 ml and in the fingers not measurable. The Raynaud's symptoms in the fingers were relieved by local heat. The record shows *that the arterial circulation was normal in the arm except in the fingers during an* attack of Reynaud's symptoms

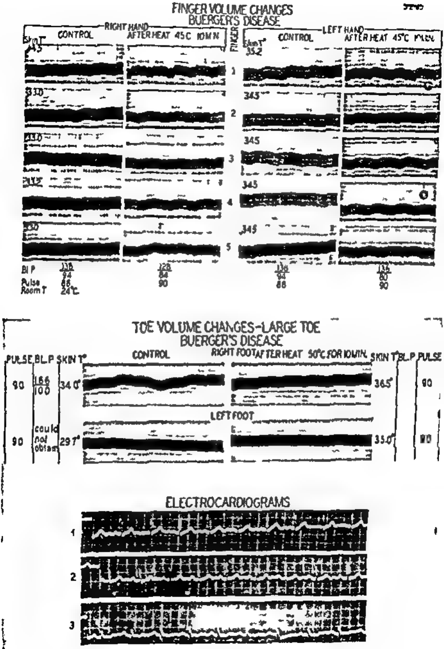

FINGER VOLUME CHANGES
BUERGER'S DISEASE
RIGHT HAND
CONTROL
AFTER HEAT 45C 10MIN
FINGER
LEFT HAND
CONTROL
AFTER HEAT 45°C 10MIN
Skin T°
35.2
34.5
34.5
34.5
34.5
1
2
3
4
5
Bl P
Pulse
Room T
24°C
TOE VOLUME CHANGES-LARGE TOE
BUERGER'S DISEASE
PULSE
BL.P
SKIN T°
CONTROL
RIGHT FOOT
AFTER HEAT 50°C FOR 10MIN.
SKIN T°
BL.P
PULSE
90
166/100
34.0°
36.5°
90
LEFT FOOT
90
could not obtain
29.7°
35.0°
ELECTROCARDIOGRAMS
1
2
3

FIG 41

normal above the elbows and at the wrist during and after the attack as illustrated in Fig 40 The details pertaining to the recording of the arterial volume pulse at the elbow and at the wrist are included in the following chapter

The significance of the above findings is obvious Surgery of the sympathetic nervous system designed to relieve digital ischemia would have to be highly selective in order to sympathectomise the fingers only without producing a sympathectomy of the whole arm

Were the latter to occur it might bring about a shunt of blood from the fingers and possible aggravation of the Raynaud s symptoms

The original conclusions set forth in the report published in 1941 are correct as borne out by the poor results of surgery as well as by the additional experimental findings indicated above

Atherosclerosis Obliterans

A number of studies were made on patients with atherosclerosis obliterans which involved the arterial circulation of the fingers No arterial volume pulse could be recorded from the fingers or toes when the obliteration was complete Studies of the arterial volume pulse elsewhere in the extremities give more data as will be set forth in the following chapter

Buerger s Disease

Many cases have been referred to the author with the tentative diagnosis of Buerger s disease Only two cases were proven by autopsy to have the disease The other cases were suffering from other arterial diseases Recordings of the arterial volume changes in the fingers and toes in one case cited above are illustrated in Fig 41 This patient is of interest principally because a complete post mortem was carried out All of the arteries of the body showed the presence of the characteristic arterial lesions For the post mortem study the author is indebted to Dr Edwin Hirsch of St Luke s Hospital Chicago

Fig 41

Recordings of the arterial volume pulse from the fingers and toes from a white male aged 40 who had symptoms of occlusive arterial disease in his legs of eleven years duration This case was proven to have Buerger s disease at autopsy The very low amplitudes or absent volume pulse in all of the fingers and large toes was not modified by local heat or by median nerve block in the fingers Also normal skin temperatures existed in the presence of proven occlusive arterial disease in both legs and arms These recordings illustrate the fact that occlusive arterial disease cannot be relieved by local heat or nerve block as is the case in functional occlusive arterial disease as illustrated in Fig 40

CHAPTER VI

THE RECORDING AND CALIBRATION OF THE ARTERIAL VOLUME PULSE FROM ANYWHERE IN THE EXTREMITIES, EXCEPT THE FINGERS AND TOES

IN *Chapter III* the important relationship between the arterial pressure pulse the arterial volume pulse and the arterial blood pressure was indicated Also it was pointed out that the arterial pressure pulse and arterial volume pulse had the same origin namely the emptying of blood from the left ventricle into an already distended elastic arterial system under pressure This important relationship will become increasingly apparent in the following presentation

FIG 4?

Recording of the arterial volume pulse and diastolic pressure in a one day old infant taken from the upper arm with a 6 cm cuff and ¼ ml calibration In this case the diastolic pressure was 50 mm Hg and the minute arterial volume pulse was 16 3 ml

The objective of the procedure described in this chapter is to record the maximal arterial volume pulse which according to Marey s principle [21] is at the diastolic pressure and to calibrate the arterial volume pulse to volume per beat or per minute and to correct these figures for overshoot undershoot and runoff

The arrangement of the instrument as used for this procedure is shown in Figs 7 and 28 The pickup mechanism (Tycos Reinforced Blood Pressure Cuff) is applied above the elbow in the usual way However one of the emerging tubes is plugged and is not used and the other is connected to the inflating bulb By means of a T tube a connection is made with the

transmitting device of the Oscillometer and with the calibration device (see Fig 28)

As already indicated it is necessary to obtain the maximal arterial volume pulse in order to record the diastolic pressure Recordings of one or two arterial volume pulses at cuff pressures from 140 to 60 mm Hg are made at 10 mm Hg increments as shown in Fig 29 To be certain that one has the maximal arterial volume pulse calibrated recordings of the arterial volume pulse at a cuff pressure 10 mm Hg above the estimated maximal arterial volume pulse and at a cuff pressure 10 mm Hg below the estimated maximal arterial volume pulse are made While making these recordings a 1 ml volume change is introduced into the system by depressing the calibration device as shown in Fig 28

From the processed recording the following information is obtained the heart rate the crest time the time of the diastolic slope the amplitude of the arterial volume pulse in horizontal lines and the amplitude of 1 ml volume change in horizontal lines To convert the arterial volume pulse to milliliters the number of intervals of the arterial volume pulse is divided by the number of intervals of the 1 ml volume change which gives the uncorrected arterial volume pulse in ml This can be corrected for over shoot undershoot and runoff by consulting Fig 24 for correction factor *K* This is accurate within an error of 7 per cent for the volume of the arterial volume pulse for heart rates of under 125 per minute Further studies are in progress to improve this degree of accuracy

Although very little work has been done on premature babies and infants a recording on an infant is shown in Fig 42

The Components of the Arterial Volume Pulse

The arterial volume pulse in the arms and legs exclusive of the fingers and toes usually reveals three peaks as follows

(a) *The first peak* The first peak is always at the crest of the arterial volume pulse when recorded at the level of the diastolic blood pressure In certain types of patients such as some with aortic regurgitation complete heart block and bundle branch block it is definitely visible on the anacrotic limb of the arterial volume pulse when recordings are made with cuff pressures above the diastolic pressure as shown in Figs 43 and 44

In other patients the first peak may be buried in the anacrotic limb It is a consistent point of reference for determining the crest time of the arterial volume pulse which has been recorded at the diastolic blood pressure The crest time is measured from the beginning of the upstroke of the arterial volume pulse to the first peak

The normal limits of the arterial volume pulse in the adult cover a very wide range depending on sex individual differences degree of physical

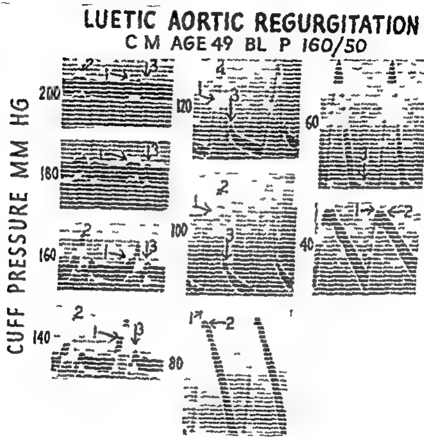


FIG 43

Recordings of the arterial volume pulse made from above the right elbow of a colored male aged 49 with luetic aortic regurgitation and blood pressure of 160/50 The recordings illustrate studies on the genesis of the three peaks of the arterial volume pulse Each record was taken with different pressures in the pickup cuff The first peak is on the ascending limb until the diastolic pressure is reached at which point it is at the crest of the pulse wave This phenomena has been observed mainly in patients with aortic regurgitation and with bundle branch block as illustrated in Fig 44

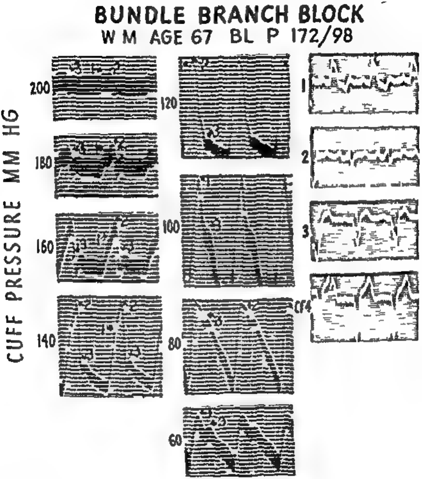


FIG 44

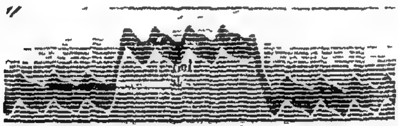
Recordings made from above the right elbow in a white male aged 67 with bundle branch block and a blood pressure of 172/98 The position of the first peak is on the ascending limb until the diastolic pressure is reached as in the case illustrated in Fig 43

fitness and somewhat on age and body build There are probably a great many other factors The approximate range is listed below

Location	*Range*
Above the elbow	100–250 ml/min
At the wrist	40–125 ml/min
Above the knee	125–250 ml/min
Below the knee	100–225 ml/min
At the ankle	40–125 ml/min

The range is given in milliliters per minute because there seems to be a reciprocal effect between the beat volume and heart rate

(b) *The second peak The second peak may be at the crest of the arterial* volume pulse when recordings are made above the diastolic blood pressure It may be at the crest following the first peak by 0 08 sec when the recordings of the arterial volume pulse are made at the diastolic blood pressure It may be on the dicrotic limb when recordings of the arterial volume pulse are made at or below the diastolic blood pressure as shown in Figs 43 and 44



ARTERIAL CIRCULATION 3 2/11 (100) (1 22) = 35 4 ml per minute CREST TIME 2 seconds

FIG 45

Recordings of the arterial volume pulse made above the right elbow from a colored male age 62 with a high grade calcific aortic stenosis Four days after the recording was made this diagnosis was confirmed at autopsy The aortic valve at that time *would only admit the head of a match Note the reduced arterial volume pulse* as well as the prolonged crest time The recorded diastolic pressure was 90 mm Hg

(c) *The third peak* The third peak is called the diastolic peak and is preceded by the diastolic notch It is present on the dicrotic limb of the *arterial volume pulse It also occurs when recordings of the volume pulses* are made from experimental models of the arterial circulation as shown in Fig 23 It is apparently due to a reflected wave

It would seem that one of the most important readings obtained from the recordings of the arterial volume pulse is a quantitative estimation of the crest time or time of rise of the arterial volume pulse *If this quantitative* estimation is prolonged beyond 0 16 sec it usually means arterial

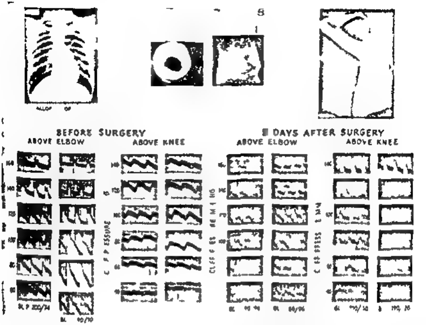


FIG 46

A composite study taken from a seventeen year old white male who had a proved coarctation of the aorta Preoperative studies indicated the hypertension in both arms and an inability to obtain an auscultatory blood pressure in the legs The recordings from the arms are what one would expect in hypertensive heart disease but the amplitude in the left arm was somewhat greater than in the right due to anatomical differences observed at operation *The recordings from the legs indicated that the blood pressure* was at least 140 mm Hg or more despite the fact that the auscultatory blood pressure could not be obtained This was partially verified at operation by palpating the distal aorta Also the recordings note a long crest time in the legs of approximately seconds as compared with a normal of 0·12 The amplitudes were also less than normal In a resection of the aorta done by Doctor John Reynolds the chest was open for five hours The specimen is shown Recordings were taken during the entire surgical procedure as well as at regular intervals following the operation The recordings taken five days after the surgery from the arms were approximately what one would expect in hypertensive heart disease while those in the legs had returned to a normal type of curve Furthermore the peripheral arteries in the legs could be palpated and the auscultatory blood pressure was found to be 200/130 in the right leg and 190/1_0 in the left l g

pathology *proximal to the site of recording* or aortic stenosis This will be illustrated by studies of aortic stenosis coarctation of the aorta asymmetrical blood pressure and atherosclerosis obliterans When the crest time is longer than 0 16 seconds the Korotkov sounds for determining arterial blood pressure by the auscultatory method may not be in the normal range of hearing and tactile discrimination is usually not sufficient to palpate the

arterial pulse although it can be demonstrated to be present by the use of the Oscillometer

High Grade Aortic Stenosis

A recording of the arterial volume pulse in a case of high grade aortic stenosis is presented in Fig 45 and illustrates the prolonged crest time of 0 2 sec and the very low amplitude of the arterial volume pulse A post mortem one week after the recording was made revealed a calcific aortic stenosis with an opening in the aortic valve which would just admit the head of a match

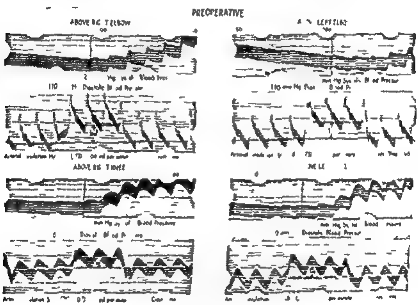


FIG 47

These recordings of the arterial blood pressure and the arterial volume pulse of the right and left arms and legs were made from a white male age 23 with coarctation and hypoplasia of the aorta Note the high blood pressures in the arms as compared with the legs Also note the very short crest times of the pulse wave in the arms as compared with the prolonged crest times in the legs The arterial volume pulse in the legs was below the normal values The dorsalis pedis and posterior tibial arteries were not palpable

Coarctation of the Aorta

A recording of the arterial volume pulse in a case of coarctation of the aorta is presented in Fig 46 The figure shows the recordings of the arterial volume pulse taken above the elbow and above the knees before and after surgery ' These recordings were made before the method of cali

bration of arterial volume pulse was developed and unfortunately were not calibrated However they do illustrate the points in question namely blood pressures could not be obtained in the legs by the auscultatory method and the pulses could not be palpated After surgery the blood pressures could be obtained by the auscultatory method in the legs and the peripheral volume pulses could be palpated The crest times of the arterial volume pulse in the legs was 0 24 sec before surgery and 0 16 sec after surgery

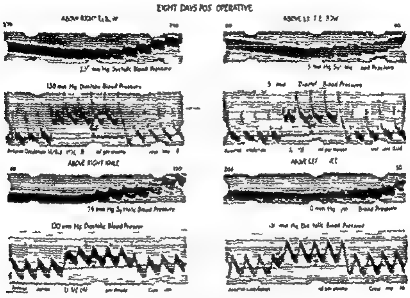


FIG 48

The above recordings are similar to those illustrated in Fig 47 repeated eight days following corrective surgery for coarctation of the aorta Note from the recordings from the legs the increased blood pressure increased arterial volume pulse and the decreased crest time The dorsalis pedis and posterior tibial arteries of both legs became palpable The results are not as striking as those from the patient illustrated in Fig 46 probably because of the associated hypoplasia of the aorta

The treatment of coarctation of the aorta by surgery is not always so successful since the patient may also have a hypoplasia of the abdominal aorta in which the surgical result may not be as effective Figs 47 and 48 illustrate such a case in a twenty three year old white male The prolonged crest times in the arterial volume pulse from the legs both before and after surgery are apparent

Age and serious heart disease have been contra indications for the surgical correction of coarctation of the aorta but the results of arterial volume

pulse studies before and after surgery on a patient with both an auricular fibrillation and coarctation of the aorta are given below Since the patient had an auricular fibrillation the results are a rough approximation The patient was a white female aged fifty two

	Recorded blood pressure	Crest time	Arterial volume pulse—per minute
	Before Surgery		
Above right elbow	145/90	0 1?	73 ml
Above left elbow	155/90	0 12	73 ml
Above right knee	111/80	0 ?6	..9 ml
Above left knee	104/80	0 ?6	23 ml
	After Surgery 5 days post operative		
Above right elbow	138/80	0 10	103 ml
Above left elbow	139/90	0 10	83 ml
Above right knee	173/100	0 12	80 ml
Above left knee	188/1?0	0 1..	92 ml

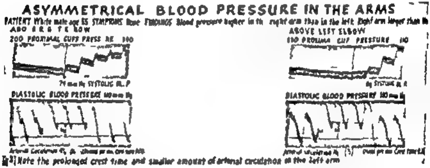


Fig 49

Recordings made from above the elbow in a white male aged 55 with a marked difference in blood pressure in the two arms The blood pressure in the right arm was 174/110 and in the left 118/110 Note the markedly increased amount of blood going to the right arm as compared with the left Also the crest time is increased in the left arm suggesting some degree of arterial occlusion to this arm Also the right biceps measured 31 cm in circumference while the left measured 27.5 The most likely diagnosis is that of a congenital defect in the left subclavian artery

Following surgery the peripheral arteries in the legs were easily palpable and showed a normal crest time This recording again illustrates the extreme importance of the crest time in indicating occlusive arterial disease proximal to the site of recording

In eight other unoperated children and young adults with coarctation of the aorta auscultatory blood pressures could not be obtained in the legs

the peripheral arteries in the legs could not be palpated and the average crest time in these eight cases was 0.26 sec as compared to a normal range of 0.08–0.16 sec

Asymmetrical Blood Pressure

The recordings presented in Fig 49 were taken from a patient who had asymmetrical blood pressure between the two arms probably due to a congenital defect in the left subclavian artery The recordings show the marked difference in blood pressures and the prolonged crest times in the left arm indicating some arterial occlusion

Cardiac Conditions

Many of the cardiac arrythmias are reflected in the recordings of the arterial volume pulse Although the Johnson Recording Oscillometer has its place in the study of the effects of these arrythmias on the circulation it does not replace the electrocardiograph since the one measures the electrical component of cardiac activity and the other the mechanical component Each instrument has its place in the study of the cardiovascular system

Atherosclerosis Obliterans

The frequency with which atherosclerosis obliterans occurs and the marked disability which it produces particularly when the arteries supplying the legs are involved makes this condition of special interest Observations in the treatment of patients with this condition are presented in the following chapter One illustration showing occlusive arterial disease from this condition in one leg is presented in this chapter The striking difference between the diseased and the normal leg is apparent The patient was a sixty three year old white male with symptoms first of pains in the right hip on walking and later of intermittent claudication in the right leg X rays showed calcium deposits in the abdominal aorta extending into the common iliac arteries Recordings of the arterial blood pressure and arterial volume pulse in both legs above the knee below the knee and at the ankles are illustrated in Fig 50 The points of interest in this case are as follows (1) visualization of arterial calcium deposits by X ray does not necessarily mean occlusive arterial disease (2) the recorded blood pressures were 102/70 in the right leg and 166/110 in the left leg (3) the crest time of the arterial volume pulse in the right leg was 0.28 sec and in the left leg 0.16 sec (4) the arterial volume pulse per minute in the right leg above the knee was 42 ml per minute and in the left leg 258 ml per minute and (5) the dorsalis pedis and posterior tibial arteries were not palpable in the right leg and were palpable in the left leg

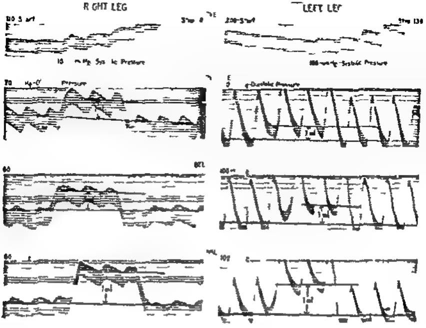


FIG 50

The upper section shows recordings of the systolic blood pressure in the legs Note the hypotension in the right leg associated with occlu ive arterial disease The lower recordings were taken at the diastolic pressure above the knee below the knee and at the ankle

Corrected Arter al Volume Pulse Expressed in milliliters

RIGHT LEG

	Diastolic pressure	Heart rate	Crest tim	A	Pulse vol change
Above knee	70 mm Hg	75	0–8	1 39	4 0
Below knee	60	75	0–8	1 3	6 0
At ankle	60	75	0 8	1 32	17 7

LEFT LEG

	Diastolic pressure	Heart rate	Crest tim	A	Pulse vol change
Above knee	110	75	0 16	0 9	58 0
Below knee	100	75	0 16	0 9	168 [illegible]
At ankle	100	75	0 16	0 9	8 5

The difference between the legs is very apparent The prolonged crest times and the decreased minute arterial volume pul es distal to occlusive arterial disease are characteristic These changes are present to an even greater degree in the three other cases reported This patient was chosen for illustration since he had a normal leg to compare with one with occlusive arterial disease

CHAPTER VII

TREATMENT OF ATHEROSCLEROSIS OBLITERANS WITH MASSAGE

INTERMITTENT claudication and rest pains or distress due to o lus ve arterial disease are now increasingly prevalent as a cause of varyin d grees of disability The principal reason for this is probably extended lon evity but the tensions of modern living may also contribute important factors Although there are a number of conditions which lead to occlusive arterial disease of the legs with symptoms of intermittent claudication and rest pains the most common cause is arteriosclerosis which includes arterio sclerosis medalis and atherosclerosis obliterans

The physiological mechanism which produces the pains of intermitt nt claudication is not well understood but it is generally believed to be due to ischemia of the involved muscles The cause of the rest pains is even less well understood as these occur in the absence of contracting muscles The current theory is that the pain of intermittent claudication is related to a metabolic by product of contracting muscle P Factor associated with muscle anoxia The work of Lewis[30] a text book review by Best and Taylor[31] and a review by Wesseler[?] summarizes the knowledge to date on the subject

There are many treatments which have been recommended for this con dition However the following statement is presented in Wesseler s review of the subject There is today no effective measure for the treatment of intermittent claudication that has gained wide acceptance Among the drugs investigated Wesseler lists calcium vitamin E theobromine methyl testosterone depropanex cytochrome C intravenous hypertonic saline solution thiouracil histamine and various sympatholytic agents In addi tion to the above Allen Barker and Hines[33] list thyroid extract and estrogens Among the aids in physical medicine Wesseler lists intermittent venous occlusion pavex and Buerger s exercises The surgical procedures are too numerous to list Tobacco has been suspected and its discontinu ance is thought to exert a favorable influence The author has made ex tensive studies of the arterial blood pressure and the arterial volume pulse before and after the use of tobacco However the results are not yet con clusive because of the complex nature of the problem It is obvious that co existing diseases such as polycythemia vera diabetes mellitus and the cologen diseases should be brought under control

One hesitates to add to so formidable a list of treatments for intermittent claudication and rest pains Moreover discussion of treatments is not the primary purpose of this chapter which is rather intended to present objective and subjective data resulting from an experimental study on the use of massage in the treatment of this condition

The objective data was obtained by controlled serial oscillometric studies and the subjective data by the clinical evaluation of the results of treatment In the past oscillometry had limited usefulness because of the lack of precision in existing oscillometers as well as the lack of proper calibration of the recordings With the Johnson Recording Oscillometer it is now possible to make comparative studies on patients over long periods of time painlessly and without arterial puncture

Methods of Study

The patients were non diabetic males with obliterating types of arteriosclerosis All had been under treatment and observation for three or more years The clinical details are given in the case studies which follow

All of the recordings were made with the patient in the reclining position Patients were required to take a 15 min rest period before each recording This rest period was originally thought to be adequate but was later revised

The arterial blood pressure was recorded in all four extremities by the method outlined in Chapter IV The calibrated arterial volume pulse was recorded in all four extremities at various levels by the method outlined in Chapter VI From these recordings as well as from other clinical and laboratory observations the degree and location of the arterial occlusions were determined

In order to ascertain the immediate effect of massage a control record of the calibrated arterial volume pulse at both ankles was made before treatment was initiated Massage was given for ½ hr to one leg by means of a hand massager weighing 2½ lb and oscillating at 60 c/s in a circular motion over a diameter of 4 mm Immediately after the massage the calibrated arterial volume pulse was again recorded at the ankles for comparison with the controls

Each patient was instructed to buy a hand massager and was trained to give his own massage for ½ hr by the clock daily for each leg or legs affected The patient returned once a month for follow up studies

The effects of the pain of intermittent claudication on the corrected minute arterial volume pulses was determined by first making a control recording at both ankles The patient was then told to walk rapidly until he had the pain of intermittent claudication and to return immediately for

further recordings which were made during the pain and after a ten and twenty minute rest period

In addition to the objective studies noted above the clinical condition of the patient was evaluated from such subjective factors as the disappearance of rest pains and increased walking tolerance

The results of these studies are presented in separate case histories for each patient and are followed by a general discussion

Case Histories

Case 1 Mr B white male age sixty three first complained of pain in the hip on walking in December 1953 Since 2 December 1954 after walking one block he developed a pain in the right calf which was relieved by resting for 1 min A general physical examination was negative except for the right leg The recorded arterial blood pressures in the arms were normal The recorded arterial blood pressure in the right leg was low at 102/70 and in the left leg normal at 166/110 The arterial pulse was normally palpable in the arms and left leg while the femoral popliteal dorsalis pedis and posterior tibial artery in the right leg could not be palpated The laboratory studies were within the normal range except for an X ray of the abdominal aorta which revealed calcium deposits extending into both common iliac arteries Recordings of the arterial blood pressure and arterial volume pulse at various levels in the legs are illustrated in Fig 50 The minute arterial volume pulses were corrected for errors of overshoot undershoot and runoff with *K* obtained from Fig 24 An examination of Fig 50 reveals that the crest times at all levels from the right leg were prolonged to 0 28 sec while the crest times at all levels from the left leg were normal at 0 16 sec Also the corrected minute arterial volume pulses were markedly decreased being 42 ml above the knee 26 ml below the knee and 17 7 ml at the ankle On the left leg they were 258 ml above the knee 168 ml below the knee and 82 5 ml at the ankle In the left leg these are within the normal range

The immediate effects of massage on the corrected minute arterial volume pulses were studied at the ankles by making control recordings The right leg was massaged for one half hour A second set of recordings were made which showed no significant change over the control recordings

The immediate and later effects of the pain of intermittent claudication were studied by making control recordings of the corrected minute arterial volume pulses at both ankles The patient was then required to walk briskly until pain developed and to return for a further recording which was made during the pain The recordings were repeated after a ten and twenty minute rest The gastrocnemius muscle was flacid during the pain as has been observed by others These recordings are illustrated in Fig 51

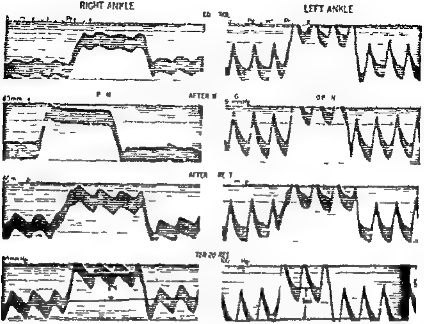


FIG 51

This figure illustrates the effects of the pain of intermittent claudication on the corrected minute arterial volume pulses and the effects of 10 and 20 min rest after the pain

Corrected Minute Arterial Volume Pulses Expressed as ml

	Diastolic pressure	Heart rate	Crest time	λ	Pulse vol change
		RIGHT ANKLE			
Control	60 mm Hg	75	0.[illegible]8	1.3[illegible]	17.9 ml
During pain	Not measurable				0.0
After 10 min rest	60	75	0.28	1.32	34.2
After 20 min rest	[illegible]	75	0.28	1.32	47.5
		LEFT ANKLE			
Control	90	75	0.16	0.92	92.0
No pain	90	75	0.16	0.92	71.2
After 10 min rest	90	75	0.16	0.92	63.2
After 20 min rest	100	75	0.16	0.92	71.2

Note the complete absence of a measurable volume pulse during the pain of intermittent claudication Also the reactive hyperemia following a 10 and 20 min rest period after the pain

This illustration shows that no arterial volume pulse was present during the pain but following a rest of 20 min the minute arterial volume pulses increased approximately 250 per cent

The patient was instructed to massage his right leg for one half hour by the clock once a day and to return for study once a month which he did faithfully

The corrected minute arterial volume pulses recorded at the ankles were at first somewhat variable since the patient did not make any effort to walk slowly while coming to the office After the profound effect of the pain of intermittent claudication was discovered the patient was instructed to get to the office with at little effort as possible In the course of the year on this management the corrected minute arterial volume pulses approximately doubled The patient could then walk at a moderate rate indefinitely without pain while previous to this form of therapy walking one block brought on pain

This case report illustrates (1) a relative hypotension in the right leg prolonged crest time of the arterial volume pulse decreased corrected minute arterial volume pulses and dorsalis pedis and posterior tibial arteries not palpable (2) a normal blood pressure in the left leg normal crest time of the arterial volume pulse normal corrected minute arterial volume pulses and palpable dorsalis pedis and posterior tibial arteries (3) no immediate effects of massage on the corrected minute arterial volume pulses (4) absent arterial volume pulse during the pain of intermittent claudication with an exaggerated response ten and twenty minutes after the pain (5) the corrected minute arterial volume pulses in the right leg improved by over one hundred per cent in the course of a year s treatment and (6) a marked improvement of walking tolerance during the course of a year s treatment with massage

CASE 2 Mr S a white male aged fifty five first came under observation on 30 October 1954 with symptoms of intermittent claudication of 2 years duration After walking about one half block the patient developed calf pains in both legs but worse in the left leg These pains disappeared after resting about 1 min and he could then walk another one half block The general physical examination was negative except with reference to the legs The recorded arterial blood pressure was 126/80 in the right arm 125/80 in the left arm 107/60 in the right leg and 78/60 in the left leg The arterial volume pulse in the arms was normally palpable and in the legs both femoral arteries were palpable while the dorsalis pedis and posterior tibial arteries could not be palpated in either leg An X ray of the abdominal aorta showed calcium plaques while X rays of both legs showed no evidence of calcium deposits in the course of the large arteries Recordings of the corrected minute arterial volume pulses at various levels

in both legs showed prolonged crest times and low minute arterial volume pulses indicating occlusive arterial disease in both legs well above the knee The immediate effects of massage as well as the effects of the pain of intermittent claudication were the same as in Case 1 The patient was trained to massage his legs with a portable massager and was told to massage each leg ½ hr daily by the clock and to return once a month for observation Objectively the patient did not improve as much as other patients as the corrected minute arterial volume pulses increased only about fifty per cent over the initial studies This is attributed to the fact that the patient could not take his massage as consistently as the other patients Subjectively he was markedly improved to the point where he could walk slowly for about a mile without pain

The same comment applies to this patient as to Case 1 except that he had occlusive arterial disease in both legs and that he did not show the marked objective improvement

CASE 3 Mr J S white male aged sixty eight was first seen on 28 September 1954 with the following complaints (1) he had cramps in the left calf muscle at night lasting as long as 15 min during which time he sat up in bed and hung his leg in the dependent position and rubbed the calf muscle to obtain relief Sometimes this gave him relief and sometimes it did not The following day the calf muscle was sore These symptoms had occurred two or three times a night for 1½–2 years (2) he developed pain on walking short distances (3) he had a scaly rash which involved the hands and forearms the left foot and foreleg and the face which had been present since 1947 The application of ointments and about twenty X ray treatments brought no relief (4) the right leg was amputated above the knee with a painful stump

The past history revealed the amputation of the right leg above the knee on 26 January 1951 for occlusive arterial disease and gangrene of the large toe and foot The uncalibrated recordings of the arterial volume pulse made at that time revealed severe occlusive arterial disease There was total absence of pulsations in the right leg The pathological report indicated that the lining of the popliteal artery showed marked fatty and fibrous changes as well as atheromatous plaques The posterior tibial artery was occluded for 3 or 4 cm and patent beyond this The anterior tibial artery was completely occluded by confluent yellow atheromatous plaques The femoral vein showed no changes The Gullian Barre syndrome was present in February 1948 with temporary paralysis of the arms trunk and legs

The essential findings of physical examination were as follows (1) amputated right leg above the knee (2) a scaly rash involving the hand forearms the left foot and foreleg and the face (3) left radial ulnar

dorsalis pedis and posterior tibial arteries were not palpable Both femoral arteries were easily palpable

The recorded arterial blood pressure was as follows right arm 128/70 left arm 78/70 and left leg 107/80

The laboratory studies were negative except for a moderate hypochromic anemia

The corrected minute arterial volume pulses in the arms and legs are as follows

	Crest Time		Corrected Minute Arterial Volume Pulses	
	Right	Left	Right	Left
Above elbow	0 14 sec	0 24 sec	155 ml	106 ml
At wrist	0 15	0 24	53 ml	38 ml
Above knee		0 24		84 ml
Below knee		0 24		22 ml
At ankle		0 24		12 ml

One notes the prolonged crest times and reduced corrected minute arterial volume pulses in the left arm and leg indicating occlusive arterial disease in the left arm and leg

The following diagnoses were made (1) occlusive arterial disease of the left arm originating above the elbow (2) occlusive arterial disease of the left leg originating above the knee (3) amputation of the right leg above the knee and (4) dermatitis of the hands and forearms the left foot and foreleg and face secondary to a chronic nutritional deficiency and (5) a moderate hypochromic anemia

After a half hour massage to the left leg with a portable massager the corrected minute arterial volume pulses were studied No immediate effect of massage was apparent as occurred in Case 1 and Case 2

The patient was trained to give his own massage to the left leg with a portable massager ½ hr daily by the clock He returned once a month for observation Also he was given one ampule of Solu B with 1 ml of 20 μg liver extract intra musculary every other day

The corrected arterial volume pulse was determined at the left ankle once a month After a year the corrected minute arterial volume pulses improved from 12 to 20 ml per minute Subjectively the jerking symptoms disappeared in about 2 weeks the rest pains disappeared gradually over the course of 2 months the dermatitis completely disappeared in six months and the walking tolerance improved to the extent that the patient could walk as far as he wished without pain It must be remembered that the patient wore a prosthesis on his right leg which prevented his walking very fast

The patient had been under treatment for a year before it was decided to study the effects of intermittent claudication pain on the arterial volume pulse but pain could not be produced by having the patient walk for fifteen minutes The results of this study are as follows

LEFT ANKLE

	Crest time	Corrected minute Arterial volume pulses
Control	0 24 sec	17 6 ml
After walking	0 24 sec	14 _ ml
After ten minute rest	0 24 sec	18 5 ml

These figures are somewhat misleading since there was a marked decrease in the arterial volume pulse which was in part compensated for by the increased heart rate *Note* This patient died suddenly of heart failure in November 1956

The same comments hold for this case as for Case I In addition this is a proven case of atherosclerosis obliterans Also the improvement in the nutritional status may have had some bearing on the improvement in his walking tolerance

CASE 4 Mr T a white male aged seventy seven was first seen in April 1953 with symptoms of intense tingling in both legs which to him were indescribable and which occurred at night and were so severe that he could not sleep He obtained some relief from sitting up in bed with his legs horizontal This distress had been present for 2 years and was more severe in the left foot than in the right He also complained of intermittent claudication of 12 years duration and when first seen could not walk more than one half block without resting The latter symptoms were more severe in the left leg than in the right He also complained of a cold sensation in his feet and the feet felt cold to the touch

The general physical examination was essentially negative except for the legs The recorded arterial blood pressure was 150/90 in the right arm and 160/90 in the left while in the right leg it was 112/90 and 115/90 in the left The radial and ulnar arteries in both arms and femoral arteries in both legs were normally palpable while the dorsalis pedis and posterior tibial arteries could not be palpated in either leg

Laboratory studies were in the normal range including X rays of the abdominal aorta and large arteries of the legs There were no visible calcium deposits The recorded minute arterial volume pulses were within the normal range in the arms The legs at various levels showed marked impairment indicating occlusive arterial disease above the knee in both legs Studies of the corrected minute arterial volume pulses recorded at the ankles showed no significant difference before and immediately after one

half hour massage with a portable hand massager The patient was instructed to massage his legs with a portable hand massager ½ hr daily per leg He preferred to have a masseur massage his legs three times a week with the conventional method and to use the hand massager as instructed on the other days Recordings of the corrected minute arterial volume pulses were made once a month for over 4 years and these figures were about three times the original controls The effects of the pain of intermittent claudication on the corrected minute arterial volume pulses were studied in a similar manner to those of Cases 1 and 2 and with similar results After two years of treatment with massage the recorded minute arterial volume pulses taken at the ankles were approximately two and one half times greater than the original control studies It is of interest to note that the crest times were 0 24 sec in the right leg and 0 32 sec in the left Symptomatically the rest pains disappeared in about one month and walking tolerance increased from one half block to eight blocks without pain in 1 year

The comments are essentially the same as those cited for Case 1 except that this patient had more pathology in both legs and the improvement was more striking

Comments and Conclusions

The accuracy of the Johnson Recording Oscillometer for recording the arterial volume pulse was evaluated in Chapter VI Under the conditions of these studies it was found to be accurate within 7 per cent In the patients included in this phase of the study the improvements in the recorded volume pulse ranged from 200 to 300 per cent Therefore the error is insignificant by comparison The lag of the instrument has been found by experiment to be approximately 0 004 sec which is insignificant and non measurable as the instrument is used

Clinically the amplitude and form of the pulse wave are important for several reasons The amplitude is important for the arterial volume pulse can be calibrated accurately to 0 02 ml in volume change which can be corrected for overshoot undershoot and runoff and the value expressed in ml per beat or per minute By this means the adequacy of the arterial circulation at a particular site in the body can be estimated and compared with future studies The form is important because it is related to crest time which can be determined with precision If it is prolonged beyond 0·16 sec it usually means occlusive arterial disease proximal to the site of recording or high grade aortic stenosis

Detailed reports on four patients with occlusive arterial disease were presented All showed a decrease in the amplitude of the arterial volume pulse as well as a change in form with prolonged crest times from the

affected extremities On repeated examinations the results remained fairly constant within the limits of physiological variations

The value of massage in the presence of severe arterial occlusions has occasionally been questioned on the grounds that it raises the metabolic requirements of the tissues and might therefore be harmful to the patient In the more than twenty patients included in this study no harmful effects were apparent On the contrary varying degrees of subjective and objective improvement were noted

No beneficial effects could be measured objectively after a single massage treatment although all patients reported subjective improvement Repeated massage brought relief of rest pains or distress in about 1 month associated with increased arterial volume pulse Further treatment led to increased walking tolerance without pain as well as a doubling in the arterial volume pulse in a year and a tripling of arterial volume pulse in a year and a half

Some inconsistencies in the recordings in early studies are thought to be due to inadequate control rest periods It was found later in the study that the pain of intermittent claudication had a profound effect on the arterial volume pulse During the pain no pulse could be measured which means that it was less than 0 02 ml while after a rest of 10 and 20 min there was a tremendous increase over the control level The explanation for this improvement is not clear It may be due to the opening up of preformed collaterals which are known anatomically to exist It does suggest that walking is beneficial to the patient

The cause for the progressive and marked improvement in these patients is not known At first it was believed to be due to the development of new collateral circulation rather than to the release of spasm in pre existing collaterals The marked improvement in the recorded arterial volume pulse shortly after the pain of intermittent claudication indicates the existence of preformed collateral circulation which is very important The release of spasm in these vessels is a major factor although new collaterals may slowly be developed

It has been noted by other investigators that on occasion there is some spontaneous improvement in patients with intermittent claudication and rest pains This was not the case in the patients reported herein as in all cases the condition was of long standing and of a progressive nature One patient Mr J S had already had one leg amputated because of inadequate circulation

Very little is known concerning the relative merits of various types of massage In this study a method was chosen which is applicable to the home treatment of ambulatory patients The instrument selected was light in weight portable sturdy and has a frequency of 60 c/s in a circular motion over a 4 mm circle Possibly a comparative study of instruments

may reveal one which is superior. The length of time of massage was also arbitrarily chosen as ½ hr per leg per day

With increased longevity, atherosclerosis obliterans of the extremities will become one of our major problems. This condition causes a great deal of suffering on the part of the patient, considerable disability and even loss of limbs. For these reasons most patients are willing to make the sacrifice in time and effort faithfully to carry out the prolonged treatment and to return for periodic checkups, especially since all patients obtained a large measure of relief, even though subjective and objective improvement was slow

CHAPTER VIII

THE ARTERIAL VOLUME PULSE FROM THE HUMAN BRAIN

THE data on the arterial volume pulse of the human brain is of purely academic interest and is presented solely as introduction to the discussion of the arterial volume pulse of the intraorbital tissues with which it is intimately related

The study of the brain was made principally on a patient with a brain tumor which was surgically removed through a trephine hole in the skull from which the arterial volume pulse could be recorded

In reference to the dynamics of the arterial circulation of the brain in 1783 Monro[1] formulated the theory that since the cranium of the adult

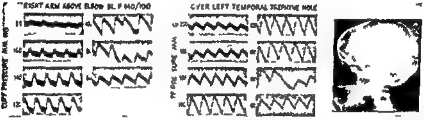


FIG 5.

Recordings of the arterial volume pulse from a patient who had had a brain tumor removed about one year before the records were taken Note in the skull picture the large trephine hole The series of recordings on the left were obtained from the right arms above the elbow The blood pressure was 140/100 The series of recordings taken over the trephine hole indicates that it took more than 200 mm Hg to neutralize the pulsatile arterial changes from the brain The entirely different character of the pulse wave may indicate that the brain has some cushioning effect upon the arterial pulse volume

is a rigid indistensable box completely filled with incompressible contents the quantity of blood contained within cannot change appreciably This work was supported by studies of Kellie[33] in 1824 and is known as the Monro-Kellie doctrine The latter study noted that changes in the volume of any one of the three major components of the cranial cavity were compensated for by changes in the other two The Monro-Kellie doctrine is not applicable to the cranium possessing defects such as trephine holes or in infants with open fontonelles

The results of this study on a patient with a trephine hole are presented

because they do shed some light on the possible compensatory mechanism in the altered arterial circulation when a cranial defect exists

In the adult when the pulsations over the trephine hole are of considerable magnitude the recordings are made from a 6 cm cuff wrapped around the head over the trephine hole The cuff is connected to the Oscillometer in the usual manner In an infant or child with open fontonelles the capsule described for use on the intraorbital tissues serves more effectively

The diastolic blood pressure can be determined as outlined in Chapter IV and calibrated recordings of the arterial volume pulse can then be made as outlined in Chapter VI

Comparative studies of the arterial volume pulse over the trephine hole and in the right arm show an entirely different contour as illustrated in Fig 52 The diastolic pressure within the brain and in the right arm were the same in 100 mm Hg An extra systole was recorded both from the brain and from the right arm with a change in the base line

The results of this study show only the character of the arterial volume pulse in the presence of a defective cranium which allows for an increased amount of blood to enter the cranial cavity with each heart beat If the Monro–Kellie doctrine is correct in the intact cranium one would expect the arterial pulse to be only longitudinal and not mainly transverse as seen elsewhere in the body for example in the arms and legs Vasodilitation would not be possible unless one of the intracranial components decreased in volume and conversely vasoconstriction could not take place unless the volume of one or both of the intracranial components became greater in volume However as will be shown in Chapter IX *The Arterial Volume Pulse of the Intraorbital Tissues* greater or smaller quantities of blood can flow through the brain with changes in the longitudinal volume pulse

At present the nature of the arterial volume pulse wave as recorded from a patient with a trephine hole in the skull or in infants before the fontonelles are closed is only of academic interest However it may be that a better understanding of the circulatory readjustments of the brain following trephining of the adult skull may lead to procedures decreasing the surgical risk to the patient Furthermore a knowledge of the changes in the circulatory system of the brain which occur between infancy and adulthood may also lead to an improved understanding of the developmental defects of the central nervous system Suggested methods of study will be indicated in the following chapter

In taking the arterial volume pulse over a trephine hole there is some element of danger In the case reported the recordings shown were taken without mishap About 2 months later an attempt to repeat the study was made and the patient went into a coma but recovered on release of the pressure

CHAPTER IX

THE ARTERIAL VOLUME PULSE FROM THE INTRAORBITAL TISSUES

THE intraorbital tissues of the human being have only one arterial blood supply which is from the ophthalmic division of the internal carotid artery[38] Furthermore under normal conditions there is considerable evidence which indicates that functionally at least there is no communication between the two sides by way of the Circle of Willis[3] However by special methods in cerebral angiography the radiopaque material can be made to pass to the contra lateral side by way of the Circle of Willis For this reason the human eye is thought to be an ideal site for recordings of a reflection of the cerebral circulation Although this may be in part true for the recording of minute arterial volume pulses it is not true for the dynamics of the cerebral circulation because the intraorbital cavity is not a closed cavity and the Monro–Kellie doctrine as cited in the preceding chapter does not apply All of the evidence indicates that the arterial volume pulse of the intraorbital tissue is mainly transverse in nature and similar to that seen elsewhere in the body with the exception of the adult intracranial cavity where because the tissues are not compressible it is mainly longitudinal in nature (see Chapter VIII) As will be shown later this is not always the case and it is possible that this may be a contributing factor in the genesis of some eye conditions

At present there are five methods listed for the study of the cerebral circulation These are (1) direct observation of the retinal circulation (2) thermocouple measurements of the temperature of the exposed brain surface or of the blood in the internal jugular vein (3) determinations of the cerebral arteriovenous oxygen difference (4) measurement of the displacement of cerebrospinal fluid during obstruction of the internal jugular vein and (5) the use of the Fick principle The present study should provide another method and because of its simplicity accuracy and safety should find a large field of usefulness

Of unusual interest in this study are the many perplexing problems observed for which no adequate explanation can be found in the literature Nothing can be found in the literature which even remotely resembles the present study and for this reason it is difficult to correlate results with statements appearing in textbooks and periodicals on the eye The author is in private practice in internal medicine but has an interest in the eye

because its delicate structure often suggests organic and functional diseases of the body Furthermore impaired arterial circulation to the intraorbital tissues might be classed as peripheral vascular disease as is impaired circulation of the legs

In this study of the arterial volume pulse of the intraorbital tissues recordings have been made on normal patients on patients with cardiac disease with cardiovascular disease with developmental differences of the arterial circulation to the eye with intracranial conditions and with eye diseases However this report is confined almost exclusively to a detailed description of the method of study with a few illustrative records

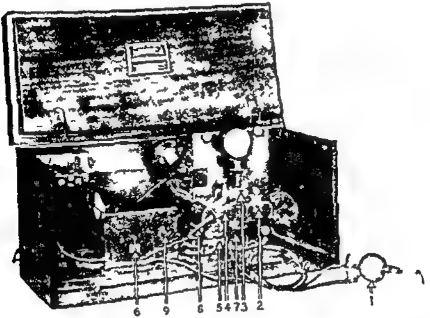


Fig 3

A photograph of the instrument with the adaptor for making recordings from the introarbital tissues the temporal artery and the cranium (1) The doubled chambered capsule ( ) stopcock from the inflating bulb (3) stopcock protecting the pressure gauge (4) the bleeder stopcock (5) the outlet from the reservoir to the calibrating device (6) the calibrating device with tub ng to the outer chamber of the capsule (1) (7) the reservoir (8) stopcock for adjusting the recording droplet of al ohol (9) light switch

Construction of the Equipment

The equipment used is the camera of the Oscillometer a double chamber pickup capsule a pressure regulating mechanism and a special metering

device The essential features of this metering device are illustrated in Fig 53 and in the drawing in Fig 54 The construction of the equipment is fully described in the legends for the above illustrations

The camera is the same as that described in Chapter I The double chamber pickup capsule is one supplied by the Cambridge Instrument Company The glycerine filled chamber has been removed and a specially constructed capsule inserted (see Fig 53 – 1) This rubber chamber is of the same dimensions as the Cambridge Instrument Chamber but the rubber dam is of 0 2 mm thickness and has an outlet so that water can be injected into this chamber under known pressure from the regulator For convenience a metal stopcock has been fastened to the back of the metal portion of the Cambridge Instrument capsule one end of which is connected to the rubber chamber and the other to the metering device (see

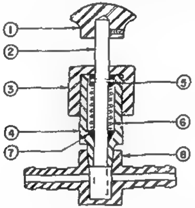


FIG 54

A machine drawing of the metering device which accurately delivers 0 1 ml volume change at will by merely depressing the plunger (1) The knob (2) piston rod (3) upper body (4) lower body (5) retaining collar (6) compression spring (7) teflon collar (8) taper joint

Fig 53 – 6) The second chamber of the capsule is connected to the recording tube of the Oscillometer

The regulating mechanism consists of a glass tube 42 mm in internal diameter and 8 5 cm long (see Fig 53 – 7) It has four outlets each with a glass stopcock connected as follows The top center stopcock (see Fig 53 – 3) is connected to a Tycos Pressure Gauge The right upper stopcock (see Fig 53 – 2) is connected to an inflating bulb a third top outlet (see Fig 53 – 4) is connected to a bleeder tube and a fourth outlet (see Fig 53 – 5) is at the bottom of the tube and is connected to one side of the metering device by means of transparent plastic tubing By using trans

parent tubing it is possible at all times to see that no air is contained in the hydraulic system

The precision metering device had to be specially constructed because no existing metering equipment could be found which would accurately deliver 0 1 ml as required The device also has a tapered joint which makes it possible to remove the essential mechanism for inspection for trapped air One end of the metering device is connected to the regulator by means of transparent plastic tubing as indicated above and the other end is connected to the special rubber capsule so that at any time the

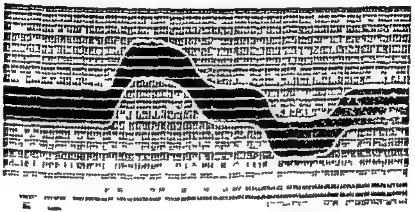


FIG 55

This figure illustrates the effects of changing the center of gravity of the capsule on the volume recording from the inner chamber of the capsule The capsule was held vertical while recording tipped horizontal with the back side down returned to the vertical position tipped horizontal with its front side down and then returned to the vertical position The volume change with each change of position was approximately 0 03 to 0 04 ml

volume of the capsule can be increased by exactly 0 1 ml of fluid by depressing the plunger of the metering device Likewise the volume can be decreased by exactly 0 1 ml by releasing the plunger

The combination of the metering device the rubber capsule and the connecting transparent tubing are filled with water in such a way that when the lower stopcock on the regulator is shut a closed hydraulic system is formed The glass chamber acts as a reservoir for water It should be emphasized that the entire mechanism is constructed to a very fine tolerance

Procedure for Recording

The procedure for making recordings of the arterial diastolic pressure is as follows

1 The patient sits erect in a chair and is told to hold his head in the same position while the recordings are being made The centre of gravity of the pickup capsule is thereby maintained The recording can also be made when the patient is reclining Fig 55 illustrates the effect of changing the center of gravity of the pickup capsule by tilting it one way or the other

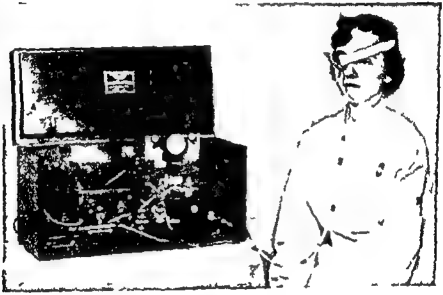


Fig 56

This photograph shows the instrument applied to a subject for recording from the intraorbital tissues

2 The deflated pickup capsule is applied over the intraorbital tissues snugly as shown in Fig 56

3 As illustrated in Fig 53 the metal stopcock on the pickup capsule (1) is in the open position the glass stopcock (2) attached to the inflating bulb is open the glass stopcock to the pressure gauge (3) is open the glass stopcock to the bleeder capillary (4) is closed the glass stopcock (5) to the metering device (6) is open and the stopcock to the recording tube (8) is open

4 A droplet of 95 per cent alcohol of a volume of approximately 0 03 ml is placed in the recording tube

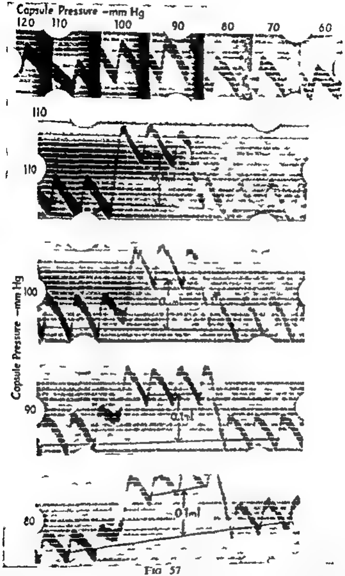


FIG 57

Recordings of the arterial volume pulse from the intraorbital tissues mad from a normal white male age 6. with no demonstrable eye pathology The upper record ing is of a single pulse wave at capsule pressures from 1 0 to 60 mm Hg at 10 mm Hg intervals The pulse wave of maximum amplitude is recorded at 90 to 100 mm Hg which is the diastolic blood pressure Calibrated recordings were then made at 110 100 90 and 80 mm Hg using a calibration of 0 1 ml The maximal arterial volume pulse in this case was found to be at a diastolic pressure of 90 mm Hg and equalled 0.069 ml per heart beat

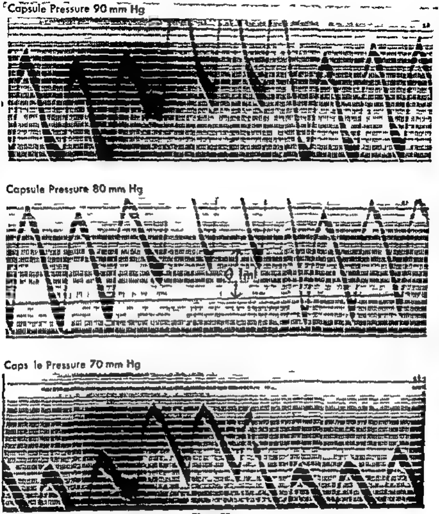


Fig 58

Recordings of the intraorbital arterial volume pulse from the right side made at various capsular pressures from a whit male age 7- with no obvious cardiac or intraorbital pathology The results are as follows

Intraorbital Arterial Volume Pulse

Capsule Pressure	Amplitude ml	Calibration 0·1 ml	Heart rate	Beat volume	Minute volume
90 mm Hg	0 13	0 085	68	0 153 ml	10 4 ml
80 mm Hg	0 145	0 07	[illegible]	0 204 ml	14 1 ml
70 mm Hg	0 09	0 07	68	0·1 8 ml	8 7 ml

The greatest volume amplitude is at 80 mm Hg which according to Marey s Principle is the diastolic pressure The minute arterial intraorbital volume pulses in this case are about twice the average normal obtained in other patients No explanation is offered

5 The pickup capsule is slowly inflated with water from the reservoir (7) until a pressure of 120 mm Hg is reached

6 The droplet of 95 per cent alcohol is adjusted for recording and the stopcock (8) is closed

7 The illumination is turned on with switch (9)

8 Recordings of two arterial volume pulses are made at pressures of 120 110 100 90 80 70 and 60 mm Hg These pressures are obtained by means of opening and closing the bleeder stopcock (4) as required

9 The pickup capsule is completely deflated by leaving the bleeder stopcock (4) open

10 The exposed tracing is developed

11 The developed tracing is examined wet and the diastolic pressure is obtained by determining the pressure at which the maximum amplitude of the pulse wave is recorded

The procedure for calibrating the arterial volume pulse is as follows

1 The method for making these recordings is the same as for taking the diastolic pressure except that recordings are made 10 mm Hg above the predetermined diastolic pressure at the diastolic pressure and 10 mm Hg below the diastolic pressure While making the recordings the glass stopcock to the metering device (5) is closed

2 Three beats are recorded the metering device is depressed while recording three more beats and then released while recording three more beats

3 The exposed tracing is then developed

In recording the wink reflexes the patient is told to wink and this reflex is recorded superimposed on the pulse wave It modifies the pulse wave for only a single beat

No effort has been made to study the effect of rotation of the eyeball on the recordings but this should present no problem

Results

Although recordings of the intraorbital volume pulse can be made with the head in any position it is necessary to keep the head in a fixed position during any given recording Otherwise an error will be introduced from the effects of gravity on the capsule and thus alter the base line This effect is illustrated in Fig 55 Movement of the orbital contents forward or backward by moving the head forward or backward might also occur but this experiment has not been done

The diastolic blood pressure in normal individuals has been found to average 100–110 mm Hg as shown in Fig 57

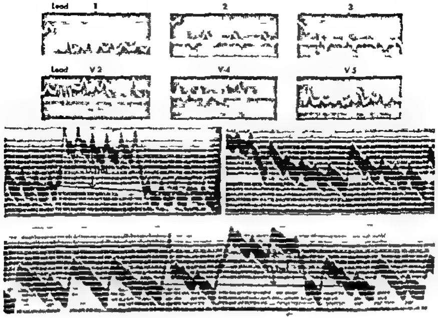


FIG 59

Recordings of the intraorbital volume puls from the right side made on a white male aged 68 who had a history of a coronary occlusion 8 years previous These recordings of the electrocardiogram and the intraorbital volume pulse were made on the patient when he had an acute attack of shortness of breath The initial disturbance of cardiac rhythm was interpreted as an auricular fibrillation from the above electrocardiogram There were continuous changes in rhythm as illustrated by the recordings of the intraorbital volume pulse It is of interest to note that although the beat amplitude of the intraorbital arterial volume pulse was below normal during the auricular fibrillation or 0 05 ml the minute arterial volume pulses were in the normal range or 7 7 ml as shown in the upper left hand illustration In the succeeding recordings note the profound changes in the arterial volume pulse with the changing rhythms which were not felt by the patient in the eye Note the wink reflex in the lower recording which takes only 0 2 sec It has been estimated that any change in the rate rhythm or stroke output of the heart is reflected into the orbital tissues within 0 04 sec

The normal arterial volume pulse taken at the diastolic pressure is in the range of 0 07 ml as shown in Fig 57 However normal recordings may give values well above this as shown in Fig 58 and well below this This indicates that the normal value covers a wide range

The form of the arterial volume pulse shows wide variations in both crest times as well as superimposed notches as illustrated in Figs 57 through 65

The arterial volume pulse is modified by any change in cardiac rate rhythm and stroke output as illustrated in Fig 59 Equipment is being constructed to determine the time required for any cardiac change to be

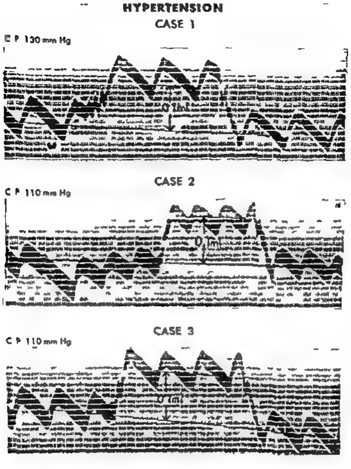


Fig 60

Recordings of the intraorbital volume pulse made from three patients with various *degrees of hypertension without evidence of diabetis or kidney disease*. Case 1 is a white male age 68 without eye symptoms but with an auscultatory blood pressure in the right arm of 250/130. The minute arterial volume pulses from the right eye are 0.045/0.08(63)=3.5 ml. Case 2 is from a white male age 60 with a high degree of myopia requiring corrective lenses of 7 diopters. Also the patient has had a retinal detachment in the left eye. The auscultatory blood pressure in the right arm was 160/110. The orbital minute arterial volume pulses were 0.03/0.08(83)=3.1 ml. Case 3 is from a white female age 44 with a right sided hemiplegia with some residual loss of function. The auscultatory blood pressure in the right arm was 190/80. The orbital minute arterial volume pulses were 0.04/0.09(75)=3.3 ml. Note that the minute arterial volume pulses in all three cases are about one half the average normal.

recorded in the orbital tissues but available evidence indicates that this occurs in less than 0.04 sec

Several recordings of the arterial volume pulse from patients with gross arterial lesions elsewhere in the body or with severe hypertensive cardio vascular disease are presented in Figs 60 and 61

Ocular conditions may or may not modify the recordings of the intra orbital volume pulse Fig 62 illustrates the recordings from a patient with homonomous hemianopsia in one eye and an artificial eye in the other socket Recordings on a number of patients with glaucoma are illustrated in Fig 63 *Fig 64 illustrates recordings on a patient with pigmentary* degeneration of the retina

The recording of the intraorbital volume pulse may be markedly modified by simple physiological procedures such as taking a forced inspiration as illustrated in Fig 65

Comments and Conclusions

This study of the arterial volume pulse of the intraorbital tissues has raised many interesting questions the first and most important of which is its relationship to the arterial circulation of the intraorbital tissues It is the opinion of the author that what is recorded is a volume pulse which is calibrated to a fixed induced volume change and not a pressure pulse The same reasoning applies as that set forth in Chapter III on the difference between the volume and the pressure pulses

The importance of the subject is set forth by Duke Elder [1] as follows

> There are few questions in the whole of ophthalmology more important and more fundamental than the physiology of the vascular circulation Not only must this form the only logical basis of a rational understanding of the pathology of many ocular diseases but inasmuch as the entire metabolism of the eye depends primarily upon it a clear understanding of the problems which it presents is of paramount importance in the physiology of this organ

Although this study is not concerned specifically with the eyeball itself the recording of the arterial volume pulse of the intraorbital tissues may provide valuable information concerning the circulation of the eyeball

The arterial volume pulse of the intraorbital tissues is a composite of (1) the action of the heart (2) the dynamics of the pulse wave itself as it leaves the heart as it is modified in its passage through the internal carotid artery and its reversion partly or wholly to its original form (3) developmental differences in the internal carotid and ophthalmic arteries (4) intracranial conditions (5) diseases of the arteries themselves (6) diseases of the intraorbital tissues including the eye and (7) elasticity of the bony roof of the orbit This indicates the complex nature of the subject

A brief discussion of the sensitivity of the instrument used for making these recordings is in order The Johnson Recording Oscillometer as

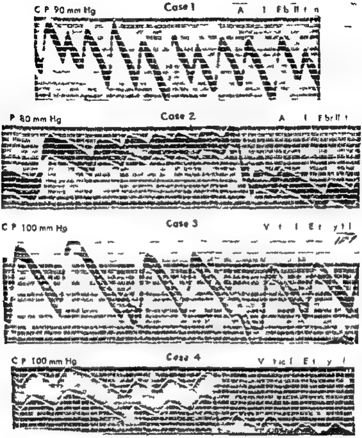


FIG 61

Recordings made of the intraorbital arterial volume pulse from four patients with cardiac arrythmias which illustrate that changes of cardiac rate rhythm and stroke output are reflected into the recordings This is thought to occur in less than 0 04 sec Case 1 was made from the right intraorbital tissues from a white female age 60 with a chronic auricular fibrillation and an associated diabetes mellitus Case ? was made from a white female aged ? with paroxysmal auricular fibrillation Cases 1 and illustrate the fact that cardiac changes associated with auricular fibrillation are recorded in the intraorbital tissues Case 3 was made from a white male *age 70 with evidence of myocardial damage bundle branch block and congestive heart failure The patient had a sinus mechanism with the exception of frequent* premature ventricular contractions Case 4 was made from a white male age 65 with gout occlusive arterial disease of the legs hypertensive cardiovascular disease evidence of myocardial damage, but with a sinus mechanism with an occasional premature ventricular contraction Cases 3 and 4 illustrate the fact that the premature ventricular contractions are reflected into the recordings of the arterial volume pulse of the intraorbital tissues

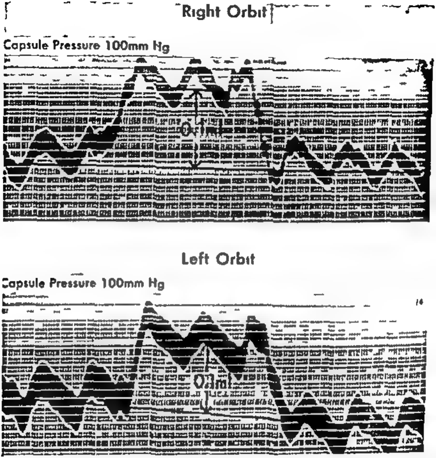


FIG. 6.

Recordings made from the intraorbital tissue of a white male age 66 who had a history of acute glaucoma of eight years duration in the left eye for which an iridectomy had been done. This in turn was followed by an enucleation of the left eye. At present the patient has an artificial eye, has hypertension of 160/106 and evidence of myocardial damage. The right eye has a homonymous hemianopsia. No intracranial lesion could be found. The arterial volume pulse of the intraorbital tissues of the right side are 0.035/0.09 or 0.039 ml and the minute arterial volume pulses 2.9 ml. The arterial volume pulse of the intraorbital tissues of the left eye plus the artificial glass eye is 0.035/0.09 or 0.039 ml and the minute arterial volume pulses 2.9 ml. The diastolic pressure was determined to be 100 mm *Hg* at which pressure these recordings were made. These results are presented without comment.

GLAUCOMA

CASE 1

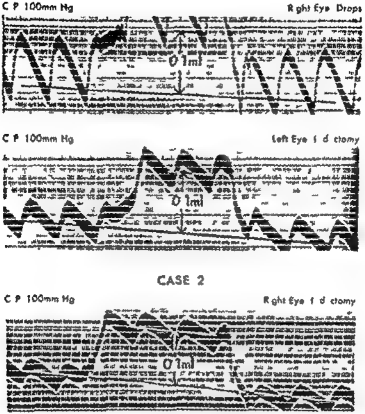


FIG 63

Recordings of the intraorbital arterial volume pulse of two patients with glaucoma Case 1 is a white male age 68 with a diabetes mellitus evidence of myocardial damage with angina amputation of the right arm at the shoulder and glaucoma The patient was using drops in the right eye and had had an iridectomy in the left eye the previous year The recordings were made at the diastolic pressure of 100 mm Hg The minute arterial volume pulses of the right eye were 0 085 (0 095 81) = 7 25 ml The minute arterial volume pulses in the left eye were 0 04 (0 09(75) – 3 3 ml Comment The amputation of the right arm at the shoulder may have some bearing on the marked discrepancy in the recordings Case a white female age 44 with a mild thyrotoxicosis, and a history of bilateral cute glaucoma of twenty years duration for which a bilateral ridectomy had been done The recording shown was made at the diastolic pres ure of the intraorbital arterial system which was 100 mm Hg The minute arterial volume pulses of the intraorbital tissues were 0 02 (0 085(75) = 1 76 ml Contrast this extremely l w value with some of the n rmal recordings

adapted to the intraorbital tissues provides a precision method for recording calibrating and timing rapidly recurring volume changes The recording is accurate to a change in volume of less than 0 002 ml will respond to rates of over 1000 per minute and has virtually no overshoot or undershoot The influence of runoff has not been determined

Although extensive studies have not been made it would seem that the normal arterial volume pulse from the adult is close to 0 07 ml plus or minus 20 per cent There are a few individuals with values far in excess

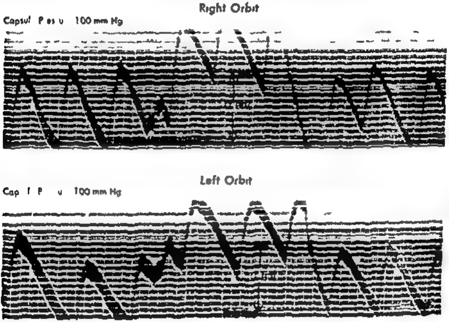


Fig 64

Recordin s of the intraorbital arterial volume puls of the ri ht and left eyes mad from a white male age 56 wi h diabetes mellitus and a diffuse pigmentary retinitis of both eyes The m nute arterial volume pulses of the right intraorbital tissues are 0 13/0 10(56) = 7 3 ml per minute and of the left 0 10/0 10(56) 5 6 ml The fasting blood sugar in this pat ent was 160 on two occasions

of this and many apparently normal subjects with normal vision with values far below this One might say that the latter subjects have less than normal ocular reserve and may present symptoms under stress

Most subjects do not complain of pain while the recordings are being made but there are a few who do complain of pain which may or may not be significant

The diastolic blood pressure of the intraorbital arteries is higher in this study than is reported by Adler for the eyeball

The wink reflex has occasionally been recorded incidental to the study The timing of the wink reflex as cited by Adler[48] is 0 36–0 4 sec In this study it has uniformly been less than 0 2 sec

No attempt has been made to measure the effects of reflex constriction or dilation of the pupil or ocular movements on the intraorbital volume but this should be possible with this equipment

It should be mentioned before closing this discussion that the bones of the skull have elasticity as discussed in Chapter XI and the bony roof of the orbit is very thin and may move considerably with pressure changes within the cranial vault If this occurs it would markedly modify the recordings obtained from the intraorbital tissues and explain some of the unusual results observed in this study Further studies are in progress on this subject

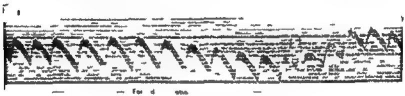


FIG 65

Recordings of the intraorbital arterial volum pulse from a white male age 52 which show the effects of a forced inspiration pos ible recession of the intraorbital tissues or a decrease in the average radius of the cranium A control study was made with a capsule pressure of 100 mm Hg Note the heart rate of 83 and the arterial volume pulse of 0 04 ml On deep inspiration the heart rate slowed to 63 the arterial volume pulse increased to 0 7 ml and the base line moved down by 0 05 ml On release of the forced inspiration the heart rate returned to 83 nd the arterial volume pulse decreased to 0 038 ml Computations indicate that the average radius of the cranium decreased by 47 μ during the deep inspiration The record also indicates the fact that chan es in the ca diovascular status are immediately reflected into the intra orbital tissues Three wink reflexes are recorded which took 0 ? sec each A comparable record taken over the forehead is illustrated in Fig 71

This me hod of recording the arterial volume pulse may not have im mediate clinical application in ophthalmology but it does open up a new avenue for the study of the various unsolved problems in the physiology of the eye with particular reference to movements of the eyeball and the circulation of the intraorbital tissues some of which are as follows

1 The possible movement of the eyeball during reflex constriction of the pupil
2 The possible movement of the eyeball during accommodation
3 The effects of blood pressure on the intraorbital circulation

4. The effects of sympathetic block on the intraorbital circulation
5. The effects of drugs on movements of the eyeball and the intraorbital circulation
6. The effects of ocular diseases on the intraorbital circulation
7. The effects of metabolic diseases on the intraorbital circulation

Further work is in progress on the development of improved equipment for the analysis of the complex intraorbital arterial volume pulse with the objective of gaining a better understanding of the genesis and nature of diseases of the orbit which are related to the circulation

CHAPTER X

THE ARTERIAL VOLUME PULSE FROM THE TEMPORAL ARTERY

THE arterial volume pulse from the temporal artery is important because of its relationship to the external carotid artery just as the ophthalmic artery is important because of its relationship to the internal carotid artery The two together are important because of their relationship to the common carotid artery

It would seem that much useful information can be obtained from a study of the arterial volume pulse of the temporal artery and intraorbital tissues in relation to congenital defects developmental defects acquired disease and the normal circulation of the intraorbital contents brain and temporal artery

A combined study of the arterial volume pulse of the intraorbital tissues as well as of the temporal artery provides data which could not b obtained by a study of one or the other alone

A description of the method of making recordings from the temporal artery is presented without much comment since the studies are not sufficient to afford a basis for definite conclusions

Method of Recording

The same equipment is used as in recording the arterial volume pulse from the intraorbital tissues The capsule is placed over the temporal artery in front of the ear as illustrated in Fig 66 A recording of one or two volume pulses is made at intracapsular pressures beginning with 140 mm Hg and at decreasing intervals of 10 mm Hg down to 60 mm Hg The recording is developed and the arterial pulse wave of greatest amplitude indicates the diastolic pressure according to Marey s Principle (Chapter IV) Calibrated recordings are then made at pressures 10 mm Hg above the diastolic pressure at the diastolic pressure and 10 mm Hg below the diastolic pressure as in recording the intraorbital arterial volume pulse

Results and Comments

The results of the studies of the arterial volume pulse from the temporal arteries differ somewhat from results of the studies of the arterial volume pulse in the extremities in that the end point is not sharp Therefore it is not as easy to determine the diastolic pressure in the temporal artery by

means of Marey's Principle. This is clearly indicated in Fig 67 which illustrates recordings of the arterial volume pulse of the right temporal artery at capsule pressure of 10 mm Hg intervals from 120 mm Hg to 60 mm Hg. The calibration which is illustrated by the change in base line is 0.1 ml

Another interesting factor in this study is the marked variation of the arterial volume pulse from the temporal artery in different subjects both with regard to form and volume. This is illustrated in Fig 67

Fig 66
The method of applying the capsule for recording the arterial volume pulse from the temporal artery

Since the temporal artery is a branch of the external carotid artery, recordings from this artery will provide some data concerning the patency and the degree of development of the external carotid artery as compared with the degree of development of the internal carotid artery as recorded from the intraorbital tissues described in the preceding chapter

The end point for determining the diastolic pressure in the temporal artery is not sharp as it is in the arms. The rather high diastolic pressure of the temporal arteries and the intraorbital arteries suggests that there might be some auxiliary blood pressure regulating mechanism to the vascular system of the head. However the work done in this area is too fragmentary to justify any positive conclusion

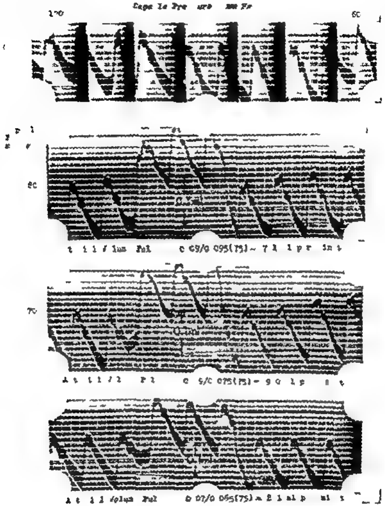


FIG 67

This figure illustrates the procedure for determining the diastolic blood pressure ove the temporal artery as well as obtaining calibrated recordings of the arterial volume pulse over the temporal artery. The upper portion shows recordings of single volume pulse waves at capsule pressures from 1 0 to 60 mm Hg. The maximum volume pulse is recorded at 70 mm Hg which is the diastolic blood pressure. Calibrated arterial volume pulses are then recorded at this pressure and at 10 mm Hg above and 10 mm Hg below this pressure in order to be certain of obtaining recordings of the maximal arterial volume pulse. Note from the record that the maximal arterial volume pulse was recorded at 70 mm Hg and gave a value for the minute arterial volume pulses of 9 0 ml

CHAPTER XI

THE ARTERIAL VOLUME PULSE TAKEN OVER THE FOREHEAD

THE present chapter is concerned with a description of making timed calibrated arterial volume pulse recordings from over the forehead. These *recordings may be of only academic interest but future studies may lead* to an improved understanding of the significance of this method for a better interpretation of the intraorbital arterial volume pulse as presented in Chapter IX. In the initial studies it was believed that these recordings *were from the arterial bed of the skin and subcutaneous tissues but certain* variations in the recordings could not be explained on the basis of known physiological principles. This study therefore may shed light on the degree of accuracy of the Monro-Kellie doctrine.

Method of Recording

The equipment used is the same as that for recording the arterial volume pulse from the intraorbital tissues and the temporal artery. The record

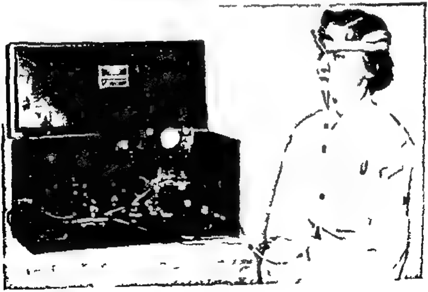


FIG. 88

This figure illustrates the procedure for applying the capsule for making recordings of the arterial volume pulse from over the forehead

ings can be made from anywhere over the cranium but for illustration the forehead is used as shown in Fig 68 The recordings can be made with the head in almost any position but all of the studies herein reported were made with the patient sitting upright

The patient sits comfortably in a chair and the pickup capsule is applied snugly to the forehead as shown in Fig 68 Serial recordings of a single

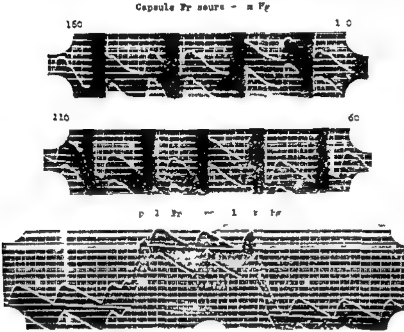


Fig 69

Recordings of the arterial volume pulse taken over the forehead from a white male age 56 with a history of untreated diabetis mellitus of twelve years duration The intraorbital recordings are illustrated in Fig 64 The patient has an associated diffuse pigmentary retinitis Recordings of single pulse waves were made with capsule pressures from 160 mm Hg to 60 mm Hg Note that there is very little difference in the amplitude of these pulse waves which indicates that these recordings result from distension of the cranial cavity and not from the arterial system of the skin and subcutaneous tissues A calibrated recording is also shown and indicates the arterial volume pulse to be 0 03 ml per beat

volume pulse are made in a manner similar to the procedures outlined for the intraorbital tissues at pressures from 160 to 60 mm Hg at 10 mm Hg intervals A calibrated recording is made at 110 mm Hg pressure The recording is then developed in the usual manner

Results and Comments

The results of such a study are illustrated in Fig. 69. They show similar amplitudes of the arterial volume pulse throughout a wide range of pressures. There is a tremendous variation in recordings taken from different individuals with amplitudes of the arterial volume pulse varying from 0.005 to 0.05 ml. The average for adults is about 0.03 ml. The method is accurate to 0.002 ml volume change.

Any change in the rate, rhythm, or stroke output of the heart is reflected in these recordings. This change is thought to occur in less than 0.04 seconds. Such a recording is illustrated in Fig. 70.

The simple procedure of taking a forced inspiration modifies the recordings as indicated in Fig. 71, which illustrates not only a change in the arterial volume pulse, but also a change in the base line.

Variations in the recordings presented are such that there is doubt as to whether the recordings reflect the arterial volume pulse from the soft tissues of the forehead, or the increased volume of the cranial cavity associated with systole.

It is apparent from the recordings presented in Fig. 69 that Marey's Principle cannot be used for obtaining the diastolic pressure. Also, that *equal arterial volume pulses can be recorded throughout the range of* diastolic and systolic blood pressures. Furthermore, the arterial volume pulse *is in excess of what one would expect to record from the skin and* subcutaneous tissues of this area. Moreover, the pressure gradient theory would *suggest* that no such arterial pressures exist in the small vessels of this area which would produce the marked volume changes observed.

These results indicate that what is recorded might possibly be an increase in the volume of the cranial vault with each heart beat. If, for the sake of simplicity, the cranial vault may be considered a sphere with a radius of 7 cm, the following computations indicate that a very slight distension of the cranial vault can explain the recorded measurements.

1. The diameter of the recording capsule is 4 cm.
2. *The radius of the skull during diastole is 7 cm*, which is also the altitude of a cone with the recording capsule as a base.
3. The volume of the basal segment of the cone during systole is 0.03 ml in the average adult.
4. Computations indicate that the altitude of the basal segment of the cone during systole will be 0.0022 cm.
5. The altitude of the cone during systole would then be 7.0022 cm, which is also the radius of the skull during systole.

This would *mean that the average radius of the adult* skull would have to increase by only 0.0022 cm during systole to produce a 0.03 ml change

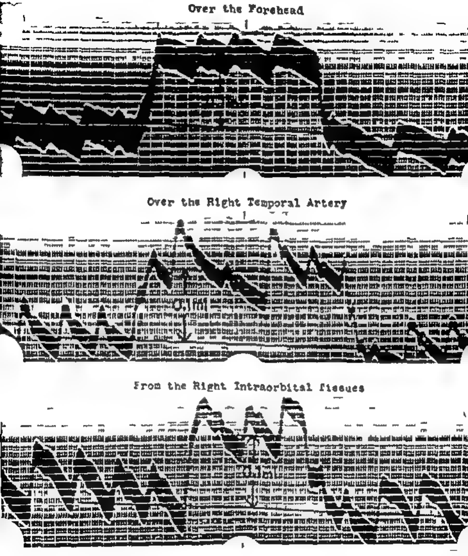


FIG 70

A composite recording of the arterial volume pulse from over the forehead the right temporal artery and the right intraorbital tissues from a patient with chronic auricular fibrillation Note that all changes of rate rhythm and stroke output of the heart are reflected into the recordings from these regions All of the recordings were made at a capsule pressure of 110 mm Hg

in the volume as outlined above This may be entirely possible The human skull is normally thought of as a rigid non distensible structure However the results of this study indicate that it is distensible within its elastic limits

The importance of this concept is that this factor must be considered in the results of the study of the minute volume pulse both from the temporal artery and the intraorbital tissues It is especially important in the inter

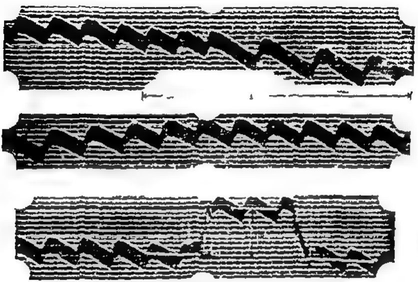


FIG. 71

Recording of the effects of a forced inspiration on the arterial volume pulse taken over the forehead at a capsule pressure of 130 mm Hg Note that the base line becomes lower the heart slows and the arterial volume amplitude becomes greater On recovery the recordings revert to the control status The lower recording is calibrated and shows the arterial volume pulse to be 0 0?/0 09 or 0 0 4 ml per heart beat The significance of this study is discussed in the text

pretation of the recordings for the intraorbital tissues when one considers the thinness of the roof of the orbit

Additional studies should be made on individuals with thick as well as thin skulls and also on children in whom the sutures are not closed to sustain this hypothesis

From this discussion one might conclude that the accuracy of the Monro Kellie doctrine would be limited by the elasticity of the bones of the cranial vault in addition to the other factors listed by Weed [39]

CHAPTER XII

SUMMARY AND CONCLUSIONS

THIS monograph on the Johnson Recording Oscillometer and its use in the study of the arterial circulation summarizes progress in the development of the instrument and its application to experimental and clinical studies of the arterial circulation in health and disease. The Johnson Recording Oscillometer makes possible the recording of arterial blood pressure in the extremities and the recording of the calibrated arterial volume pulse without arterial puncture or pain from anywhere in the extremities the temporal artery the intraorbital tissues the brain and the cranium in adults children infants and premature babies

The instrument is a precision timed recording oscillometer which provides a means of obtaining a permanent calibrated record of the arterial volume pulse. It is built to fine tolerances. The recording droplet of 95 per cent ethyl alcohol changes form instead of position in recording the arterial volume pulse. This fact indicates that only molecular resistance is involved for the recording of volume changes. The lag normally is not measurable. The recordings are accurate to 0 002 ml of volume change from the fingers toes temporal artery intraorbital tissues and the skull and to 0 02 ml volume change from the extremities exclusive of the digits. It has eight rapidly interchangeable speeds which make it possible to spread recordings of individual pulse waves for detailed analysis. The timing of the record is comparable to that of the electrocardiogram or 0 04 sec. The equipment is portable and can be taken to the patient s bedside. Good recordings can be made in daylight and recordings of the arterial volume pulse can be made with the patient in any position. Extraneous factors such as the tremor of severe Parkinson s disease do not interfere with recordings. With a suitable adaptor on a lantern slide projector the recordings can be projected on a screen for visual observation by groups

The differentiation between the arterial pressure pulse and the arterial volume pulse is implicit in this study. The arterial volume pulse is what the Oscillometer records what the finger feels when palpating the arterial pulse and what causes the oscillation in the blood pressure dial when taking the blood pressure. *Although arterial pressure change is associated* with these phenomena the arterial volume change is of prime importance and forms the basis of this study

The pressure changes in the arterial system are very important clinically. Although it has been known since 1924 that differences in blood pressure

can be present in all four extremities this has not been generally recognized The procedure for recording the arterial blood pressure in all four extremities with the Oscillometer is described This method uses mechanical principles in contrast to the Korotkov sounds used in the conventional method It is thus possible to record blood pressures by means of the Oscillometer when the Korotkov sounds are not in the range of hearing The application of this procedure to fifty one patients is presented The results demonstrate that it is possible for the same individual to have normotension hypotension and hypertension as evidenced by the recording of the blood pressure in all four extremities The importance of these findings to current therapy for hypertension is indicated by the severe aggravation of the symptoms of occlusive arterial disease of the legs when hypertension of the arms is reduced through the use of some of the new anti hypertensive drugs

The procedure for recording the volume pulse of the fingers and toes with ease and precision is described This method makes possible a better understanding of the normal physiology of the circulation as well as the abnormal physiology of some clinical conditions involving the digits The usefulness of the oscillometric procedure is illustrated in the study of functional and organic diseases of the digital circulation The application of local heat and nerve block in the digits produced a markedly increased volume pulse in normal patients and those with vasospastic conditions while in the presence of organic disease this did not occur

A study of Raynaud s syndrome atherosclerosis obliterans and Buerger s disease by this method is presented In the presence of Raynaud s syndrome the changes observed indicate that arterial circulation of the arm to the wrist is normal during the blanching stage This suggests that the blanching may not be due to an active vasospasm but to the diversion of blood through the palmar arch This would indicate that surgery of the sympathetic nervous system for the treatment of Raynaud s syndrome would have to be highly selective to sympathectomise the fingers only without producing sympathectomy of the arm with the possible aggravation of the diversion of blood from the fingers This study also showed that the arterial volume pulse of the fingers returns to the control level within thirty five days following this type of surgery

The components the time relationships and the amplitude of the arterial volume pulse are important as part of the study of the arterial circulation The first peak of the arterial volume pulse may be buried in the ascending limb of the pulse wave when pressures in the pickup cuff are above the diastolic pressure or may be plainly visible on the ascending limb with these cuff pressures particularly in the presence of bundle branch block and severe aortic regurgitation When the pressure in the pickup cuff is at

the diastolic level it is always at the peak of the pulse wave The first peak is important in this study because it is used as a point of reference for determining the crest time The second peak is at the crest of the pulse wave with pressures above the diastolic level in the pickup cuff and at or slightly below the crest with pressures in the pickup cuff below the diastolic level The third peak is the diastolic peak and is preceded by the diastolic notch This study confirms the fact that the third peak may be due to a reflected wave The time of rise or crest time of the arterial volume pulse is measured at the diastolic pressure from the beginning of the volume pulse to the first peak and is normally 0 08–0 16 sec If prolonged beyond this it usually means high grade aortic stenosis or occlusive arterial disease proximal to the site of recording When the crest time is prolonged beyond 0 16 sec the amplitude of the pulse wave is decreased and the Korotkov sounds are usually out of the range of hearing thus making it impossible to use the ausculatory method for taking blood pressure The amplitude of the volume pulse is calibrated in milliliters and is corrected for overshoot undershoot and runoff by suitable correction factors The amplitude varies with age body build physical condition and the presence of many diseases Any change in the rate rhythm or stroke output of the heart is recorded in the arterial volume pulse within 0 04 sec

The specific study of the components the time relationships and amplitude of the arterial volume pulse was made from four patients with intermittent claudication associated with atherosclerosis obliterans but without evidence of diabetis These patients were studied before and after treatment with massage All had a relative or actual hypotension in the affected leg or legs a prolonged crest time and decreased minute arterial volume pulses Ausculatory blood pressures could not be obtained in the legs and the dorsalis pedis and posterior tibial arteries could not be palpated No immediate effect of a single massage on the arterial volume pulse could be demonstrated Daily massages for one year doubled the minute arterial volume pulses No arterial volume pulse could be recorded during the pain of intermittent claudication and the arterial volume pulse increased 300 per cent after a 20 min rest following the pain of intermittent claudication After repeated massage for one month the rest pains disappeared The walking tolerance without pain increased from about one half block to one mile following daily massage for one year The beneficial effects of daily massage in the patients is believed to be due to the opening of pre formed capillaries which are known anatomically to exist

The arterial volume pulse was recorded from the human brain through a trephine hole in the skull Although this study is of purely academic interest it serves as an introduction to the study of the arterial volume pulse from the temporal artery the intraorbital tissues and the forehead

The recordings of the arterial volume pulse from the intraorbital tissues the temporal artery and the forehead require a special adaptation of the Oscillometer The results of these studies indicate that in the adult the average arterial volume pulse from the temporal artery is 0 05 ml from the intraorbital tissues 0 07 ml and that an increase in the average radius of the skull of twenty four microns occurs during systole Studies from patients with cardiac arrythmias illustrate that the disturbances of rhythm are reflected into these recordings It has been estimated that any changes in rate rhythm or stroke output of the heart is recorded from these sites within 0 04 sec Recordings of the intraorbital volume pulse from patients with glaucoma hypertension and other eye conditions are presented without comment because of the complex nature of the subject It is believed that the amplitude of the latter recordings are in part determined by the elasticity of the roof of the orbit which pushes the intraorbital contents forward with each systole The study of the arterial volume pulse taken over the forehead indicates that the human adult skull is not a rigid non distensible structure as indicated by the Monro-Kellie doctrine but is sufficiently elastic to distend with each heart beat The enlargement is easily measurable by the oscillometric method

In conclusion it should be emphasized that the primary objective of this monograph is to describe the Johnson Recording Oscillometer its sensitivity and its accuracy and to indicate its present and potential usefulness in experimental and clinical medicine

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